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NOISE INVESTIGATION AND REPAIR OF THE EBR-II INTERMEDIATE HEAT EXCHANGER

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EBR-II Project

August 1971

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

On the night of November 14, 1970, a loud banging noise was heard in the vicinity of the EBR-II intermediate heat exchanger (IHX). Indications were that the noise source was within the IHX inlet pipe. A port for access to the IHX internals was installed on the inlet-pipe elbow over a rectangular hole cut in the elbow. Visual examinations using both a periscope and a remote TV system revealed that of the two support clips holding a 1-in.-dia evacuation tube in place, the top clip was loose and the bottom clip was missing. This condition allowed the evacuation tube to move because of the secondary-sodium flow stream and vibrate against the wall of the 12-in.-dia inlet pipe. Evidence of wear on both the 12-in. pipe and the 1-in. tube was found.

The upper clip was removed; the evacuation tube was cut at the top and bottom and removed. The lower clip was not found.

The section cut out of the inlet elbow was rewelded in place and the secondary system was restored to operational status. Quiet operation of the IHX verified that the repair was successful.

I. INTRODUCTION

Experimental Breeder Reactor II (EBR-II) is an important part of the AEC's Liquid Metal Fast Breeder Reactor program. Knowledge and experience gained from the operation and maintenance of the facility will be invaluable to the design of future reactors of this type. The EBR-II facility has been described in detail previously.[1,2]

This report describes the investigation and repair activities associated with correction of an unusual noise emanating from within the intermediate heat exchanger (IHX). The noise was first noted on November 14, 1970, during normal full-power operation of the reactor. Qualitatively, the noise could be described as similar to that made by a cable slapping against a flagpole in a high wind.

The noise source was traced to a 1-in.-dia evacuation tube located in the inlet pipe of the IHX. Remote visual examination through an access hole cut into the secondary-sodium IHX inlet line established that two evacuation-tube support clips were not in their originally installed condition. The upper clip was sprung open, and the bottom clip was missing. The upper clip was removed; the evacuation tube was then cut off at the top, inside the inlet pipe, and at the lower end, near the bottom of the IHX, and removed.

A search for the missing clip was not successful. However, the flow velocities have been evaluated and the conclusion reached that the clip would not levitate. Even if the flow should rock it back and forth, it would not cause any damage if still located in the diffuser-trough assembly near the bottom of the IHX. There is a possibility that the broken clip has migrated into the stagnant volume between the diffuser troughs and the IHX bottom head, where it would remain. Each trough has two 1/2-in. drain holes, so the clip could have worked its way through a drain hole into that volume.

TV examination of the diffuser-trough assembly, while its components were being pushed and pulled on, indicated that all structures were intact.

The access port was closed by rewelding the cutout section back into the 12-in. inlet pipe. The entire secondary system was then returned to normal operation. As the flow of sodium in the secondary system was increased, noise monitoring of the IHX revealed nothing other than normal background vibrations.

The elapsed time between the first observation of noise and the return of the plant to normal operation was three months. Concurrently, numerous other scheduled plant-maintenance items and modifications were completed. The most notable of these was inspection of the No. 1 primary-coolant pump.[3]

II. DESCRIPTION OF THE INTERMEDIATE HEAT EXCHANGER

The IHX is located in the reactor building within the primary tank (as shown in Fig. 1). The primary coolant loop is shown in Fig. 2. The primary sodium from the reactor passes through the shell side of the tube bundle and returns to the primary tank. The nonradioactive secondary sodium flows through the tube side to remove heat from the primary circulation system.

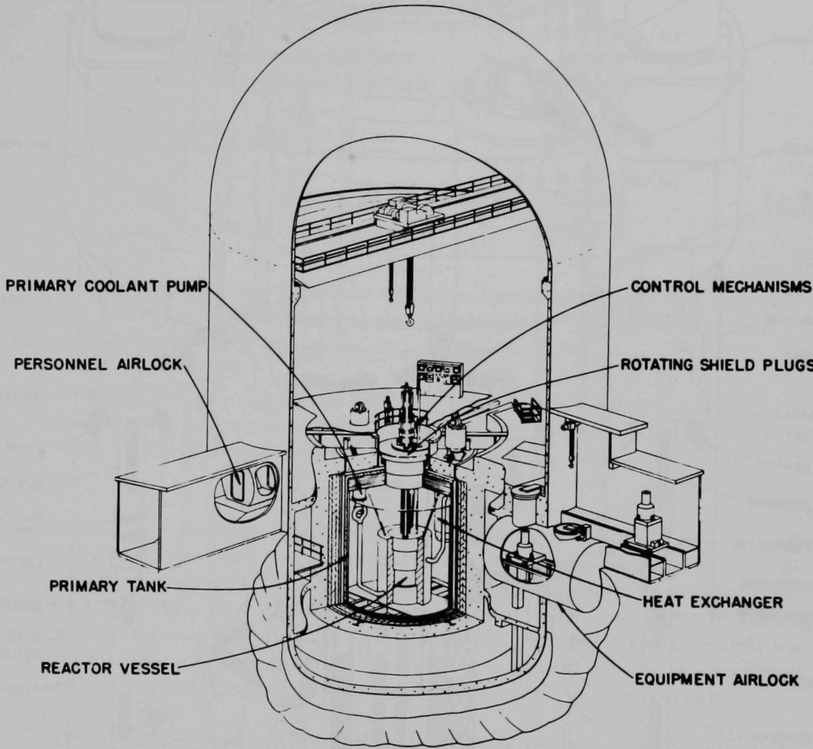


Fig. 1. Cutaway View of Reactor Building. ANL Neg. No. 103-P5437.

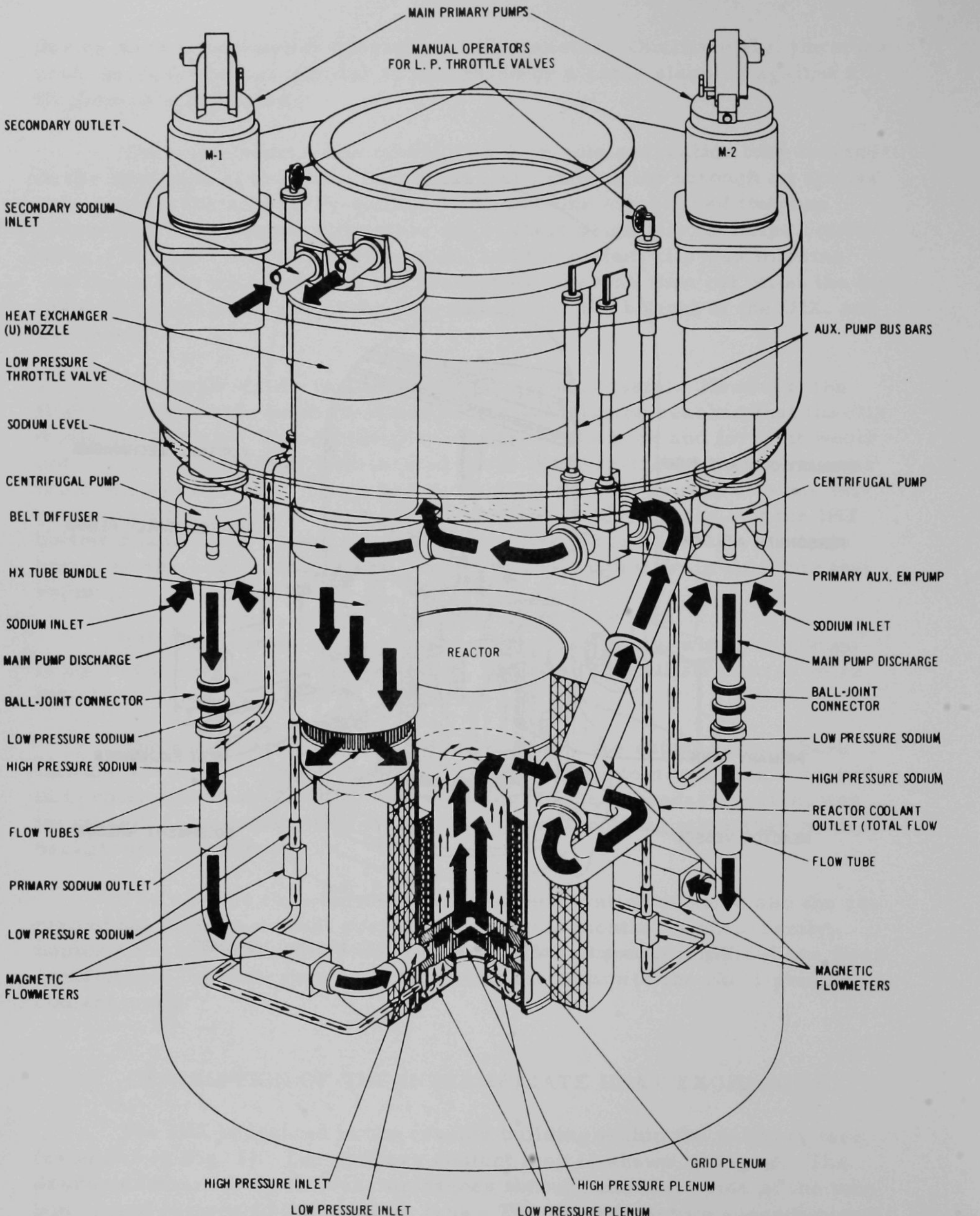


Fig. 2. Primary Coolant System. ANL Neg. No. 103-N5102.

The nominal operating parameters of the IHX during 62.5-MWt reactor operation are listed in Table I.

TABLE I. Operating Parameters of IHX

Primary Sodium Flow	
a. Flow rate	3.8×10^6 lb/hr
b. Inlet temperature	883°F
c. Outlet temperature	700°F
Secondary Sodium Flow	
a. Flow rate	2.4×10^6 lb/hr
b. Inlet temperature	588°F
c. Outlet temperature	873°F

The IHX assembly consists of three basic sections: (a) the well casing, (b) the tube bundle, and (c) the shield plug. Figure 3 gives an overall view.

The entire tube bundle is immersed in liquid sodium at 700°F. The tube bundle is of conventional tube and tube-sheet design, having 3026 tubes of Type 304 stainless steel with 5/8-in. OD and 0.049-in. minimum wall thickness.

Secondary sodium enters the 12-in. inlet line that passes through the center of the tube bundle to the bottom of the heat exchanger. At the bottom, the sodium is deflected 180° by a diffuser-trough assembly consisting of several nested half tori. The sodium then flows upward through the tubes to the outlet plenum, picking up heat from the primary sodium, and returns to the sodium boiler building for continuation of the thermal cycle into the steam-generation and electrical-production phases.

The primary sodium enters at the top of the IHX, is distributed around the inlet plenum by a belt diffuser, and then flows down past the tubes in the opposite direction to the secondary-sodium flow. The primary sodium flow is further controlled for uniform distribution around the tubes by an upper and lower orifice plate.

The tube bundle, supported from a shield plug, extends through a well casing welded to the underside of the primary-tank cover. The well casing extends into the liquid sodium and supports the end of the reactor-outlet piping along with the belt diffuser. A borated-stainless steel neutron shield comprises the lower portion of the well casing. This shield is designed to reduce activation of the secondary sodium and the stainless steel of the structure.

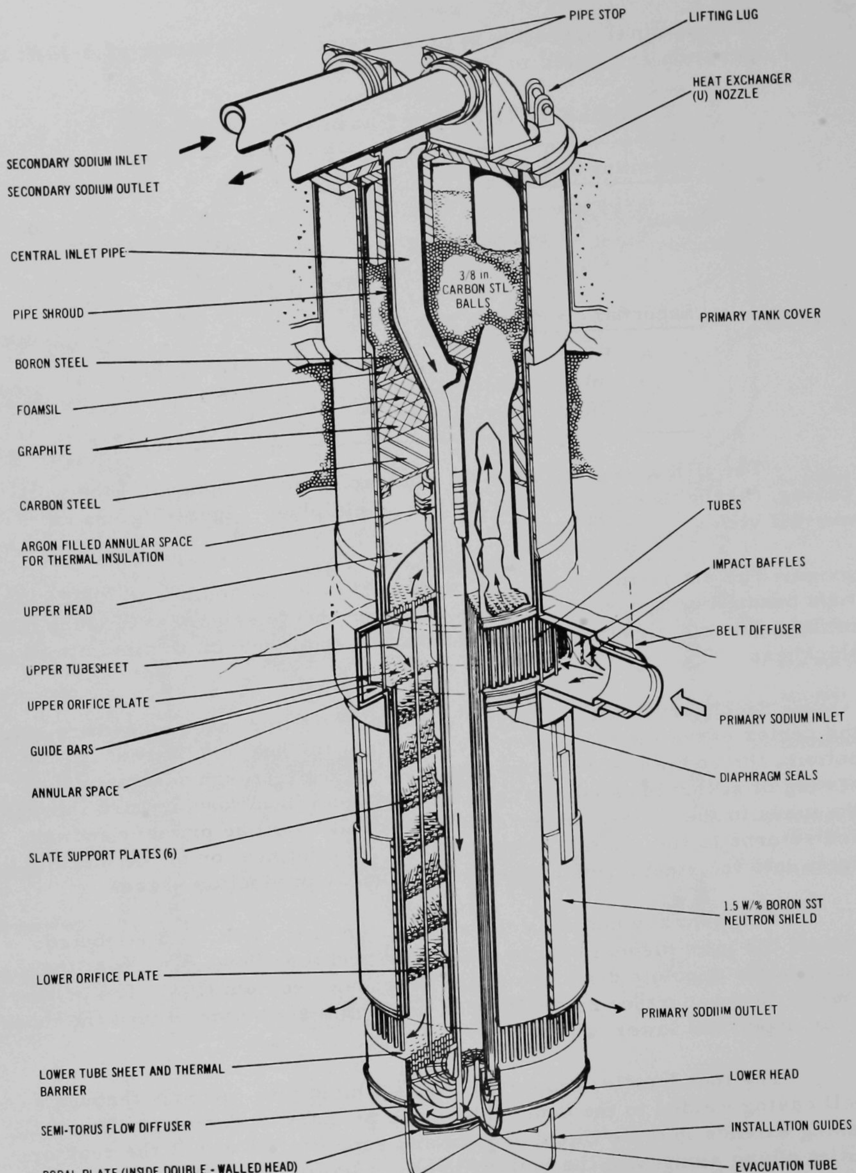


Fig. 3. Overall View of IHX. ANL Neg. No. 103-M5847 Rev.

The IHX shield plug completes the biological shielding of the primary-tank cover, supports the weight of the heat exchanger, and contains the secondary inlet and outlet pipes for the heat exchanger. Both pipes incorporate an offset pathway through the shield to reduce radiation streaming.

The IHX is assembled by sliding the tube bundle into the well casing. Diaphragm seals are provided between the bundle and the casing to minimize leakage around the tube bundle. This design permits removal of the tube bundle for repairs or replacement.

A 1-in.-dia stainless steel tube was located inside the inlet pipe (as shown in Fig. 4) for the purpose of evacuating the secondary side of the IHX in the event that the IHX needed to be removed from the primary tank. This tube penetrated the inlet pipe at the inlet elbow above the shield plug and followed the wall of the inlet pipe to the bottom of the IHX, where it was socket-welded into a stainless steel terminal piece. This terminal piece penetrates and is welded to the diffuser-trough assembly, then terminates against the inside of the lower head of the IHX. The evacuation tube was anchored to the wall of the inlet pipe in two places by 1/4-in.-dia stainless steel rods (support clips) welded to the side of the inlet pipe and bent around the tube.

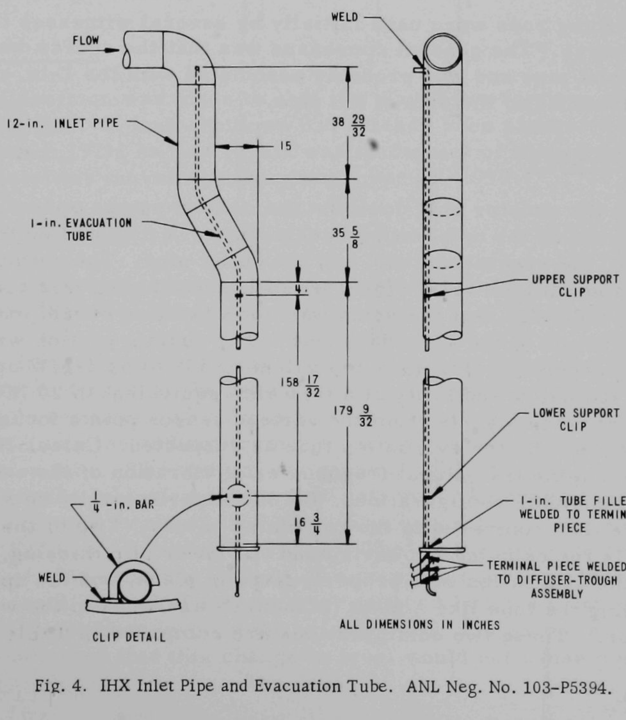


Fig. 4. IHX Inlet Pipe and Evacuation Tube. ANL Neg. No. 103-P5394.

The IHX was put into operation with initiation of secondary-system flow in August 1963. Continuous flow in the secondary system is required, even when the reactor is shut down to remove reactor afterheat; thus, the IHX had accumulated approximately 44,000 hr of operation by November 14, 1970. Operating conditions had varied since 1963 as the operating power level of the reactor was gradually increased to 62.5 MWt. There had been no previous malfunctions of the IHX.

III. CHRONOLOGY OF INVESTIGATION AND REPAIR

This section describes the sequence of the IHX investigation and repair. The intent is to show how each phase of the operation arose and to describe the relative success or failure of the steps taken.

November 14, 1970

A loud banging noise was heard in the vicinity of the IHX during steady 62.5-MWt full-power operation of EBR-II. The noise has been described as like a cable slapping against a flagpole in a high wind. A series of loud slaps would be followed by a short period of quiet and then by resumption of slapping.

Listening rods were used initially by several witnesses to pinpoint the noise source. The general consensus was that the source was located within the inlet pipe and was probably associated with the 1-in.-dia evacuation tube fastened to the side of the pipe.

November 16, 1970

With the reactor shut down but the coolant pumps operating, recordings were made of the noise using accelerometers mounted on the inlet pipe (two places), the evacuation tube, and the outlet pipe. The primary and secondary sodium flow were varied independently during this investigation. The results indicated that the noise was not a function of the primary flow but was a function of the secondary flow. The audible portion was most intense at a secondary flow rate equivalent to 50- to 62.5-MW operation and decreased below audibility at a flow rate equivalent to 30 MW. The intensities of noise signals from the various sensor points focused attention on the inlet pipe and the evacuation tube as suspected. Calculations were made to determine the natural frequencies of vibration of the evacuation tube for several possible configurations, and the experimentally determined values were then compared to the calculated values. Two of the configurations used in the calculations envisioned the lower clip missing, the top and bottom of the evacuation tube properly fixed in place, and the upper clip either holding the tube like a pivot (pinned) or anchored to the wall as a fixed support. These two configurations are compared in Table II.

TABLE II. Comparison of Measured and Calculated Resonant Frequencies of Evacuation Tube in Sodium

Measured Frequency, Hz	Calculated Frequencies, Hz	
	Fixed at Clip	Pinned at Clip
4.0	5.0	3.45
12.2	13.9	11.3
20.1	24.8	21.3
26.2	44.6	40.0
40.2		

Except for the 20.1- and 26.2-Hz frequencies, the measured data fell between the calculated limits defined by the fixed and pinned supports, and typically were closer to the values calculated for the pinned (or loosely held) case. These observations supported the supposition that the evacuation tube was the cause of the noise.

Appendix A gives the details of the calculations for sodium flow (summarized here) and for an empty IHX inlet pipe. High frequencies associated with the inlet pipe itself are also measured and compared with calculations in Appendix A.

November 16, 1970

The decision was made to shut the plant down for investigation and repair of the IHX. A long shutdown had already been planned for EBR-II for January-March 1971, so this repair was made part of that shutdown, and the beginning date was moved ahead to November 16, 1970.

November 18-22, 1970

The secondary-loop sodium was drained into the secondary-sodium storage tank. The IHX does not drain because it is a low point in the system.

The integrity of the evacuation tube was checked by bubbling argon through it to confirm that the required argon pressure matched the head of sodium within the inlet pipe. An annular, linear-induction EM pump was then used to pump the sodium from the secondary side of the IHX through the evacuation tube. The sodium was pumped to the primary tank through the nozzle for the fuel-element rupture detector. An overall view of the piping arrangement is shown in Fig. 5. The connection of the evacuation tube to the EM pump is shown in Fig. 6. The evacuation-tube penetration of the inlet pipe is shown in Fig. 7. The pumping operation took about $4\frac{1}{2}$ hr, and about 730 gal of sodium were pumped into the primary tank. This raised the sodium level in the primary tank approximately 3 in. An evaluation indicated that this change in level would not cause operational difficulties.

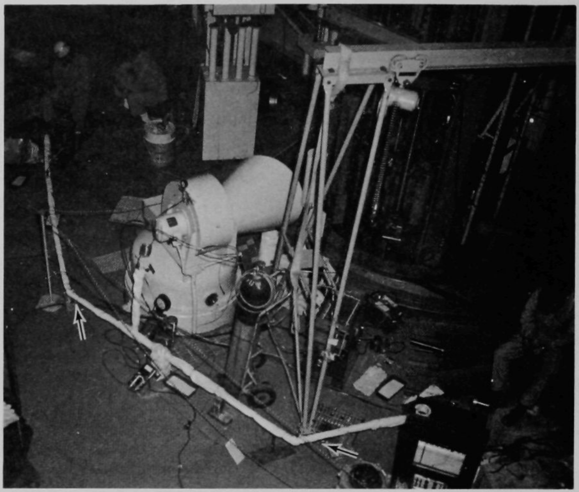


Fig. 5. Piping for Pumping Sodium from Secondary Side of IHX. ANL Neg. No. 103-N5596.

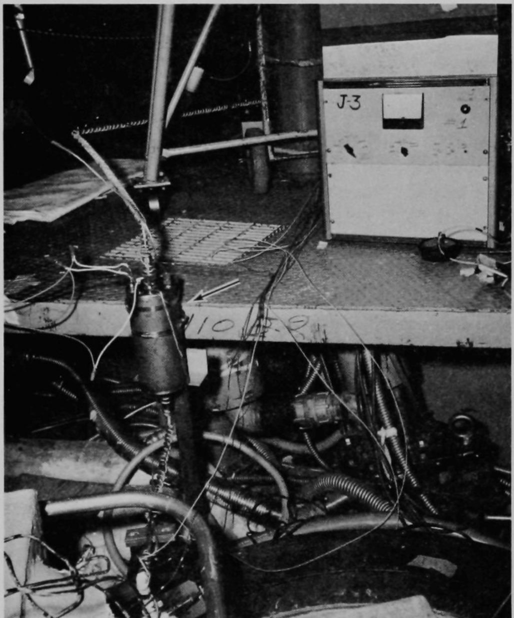


Fig. 6

EM Pump Used for Pumping Sodium from IHX. ANL Neg. No. 103-N5585.

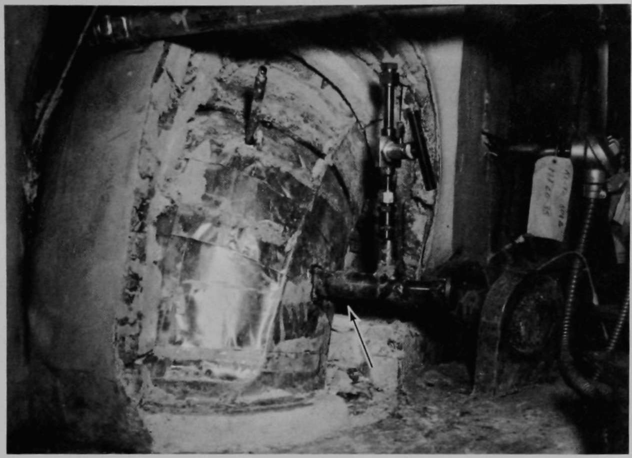


Fig. 7. Evacuation Tube Penetrating IHX Inlet Elbow. ANL Neg. No. 103-N5616.

November 18–December 7, 1970

A mockup of the 12-in. inlet pipe was constructed of carbon steel. A stainless steel tube was installed to duplicate the evacuation tube. Figure 8 shows the mockup during fabrication in the EBR-II machine shop.

Fig. 8

IHX Inlet-pipe Mockup during Fabrication. ANL Neg. No. 103-N5692.

The mockup included an access hole in the elbow identical to that to be cut in the inlet elbow of the IHX. An access port with sliding shutter, which eventually was installed on the IHX, was initially checked out on the mockup. The mockup was installed in the pit of the Inspection and Testing Facility. The pit was of proper depth to just contain the mockup, as shown in Fig. 9. Figure 10 shows the top of the mockup during checkout of the periscope. The mockup proved to be a valuable aid in determining that tools, investigative equipment, and procedures worked properly before they were used in the IHX.

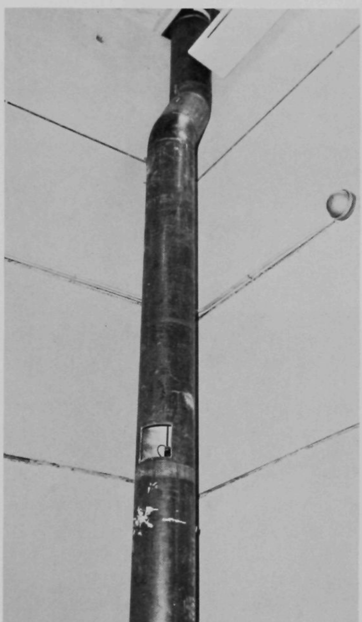


Fig. 9. Inlet-pipe Mockup Installed in Inspection and Testing Facility Pit. ANL Neg. No. 103-N5734.

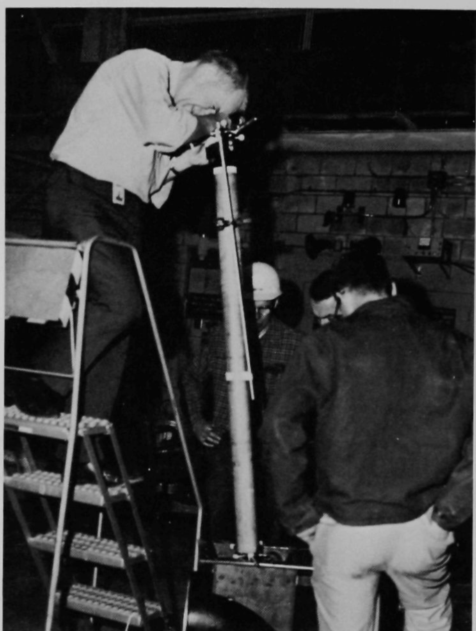


Fig. 10. Checkout of Periscope in the Inlet-pipe Mockup. ANL Neg. No. 103-N5735.

December 8-11, 1970

A trial 6 x 9-in. section was cut from a duplicate stainless steel elbow to develop the necessary procedures for removal and reinstallation of the cutout section in the IHX. (Section IV describes the cutting and welding techniques developed.)

The IHX inlet-pipe elbow was examined ultrasonically to determine wall thickness. The thickness was found to be 0.25 in., which agreed with the fabrication drawings.

December 14-15, 1970

The cutout section was ground out of the IHX elbow but left taped in place. The access port was tack-welded in place and sealed to the elbow with silicone rubber (RTV). The pressure of the argon cover gas in the secondary system was reduced to about 1 in. H_2O. The cutout section was then removed from the elbow and a Plexiglas cover plate installed on the access port to seal the system. (Section IV gives details of the access port.)

A first view through the Plexiglas cover, using a flashlight for illumination, showed that the upper clip was still in place and the evacuation tube intact, as far as could be seen.

November 16–December 10, 1970

Equipment was designed and fabricated for examining the interior of the IHX inlet pipe. Several approaches were included as alternatives and design and fabrication carried on in parallel. The equipment included a periscope-type viewer, a borescope, closed-circuit TV, a high-intensity quartz lamp for internal lighting, and miscellaneous clamps and brackets to support the various items. (The periscope and TV system are described in Sect. V.) Cover plates were designed to fit the flange of the access port and were provided with flexible adapter sleeves and windows as necessary for the particular IHX entry planned. Figure 11 shows the cover plate in place on the access port for penetration of the periscope; Fig. 12 shows the cover plate for the first version of the TV system. Each cover plate provided access and sealing of the primary device, plus a means of inserting a secondary lighting unit, as well as providing a Plexiglas window to give visual assistance in guiding tools through the access hole and inlet-pipe elbows.

As the examination progressed to the repair stage, the more complicated cover plates gave way to simple, large plastic bags with holes cut as necessary and tools sealed to the bag with tape to contain the cover gas. This change in technique was justified, as it was found that the cover-gas pressure could be maintained slightly positive and that the incoming circulating-argon temperature was typically about 50°F. With the primary-tank temperature reduced to 250-300°F, the presence of sodium vapor was not detectable.

A high-intensity quartz lamp was borrowed from the Fermi facility; this lamp had been designed for and first used in the examination and repair of the Enrico Fermi Atomic Power Plant following the fuel-melting incident of 1966. The lamp was adapted as described in Sect. V.E. The light intensity was adjustable to accommodate the needs of the particular viewing.

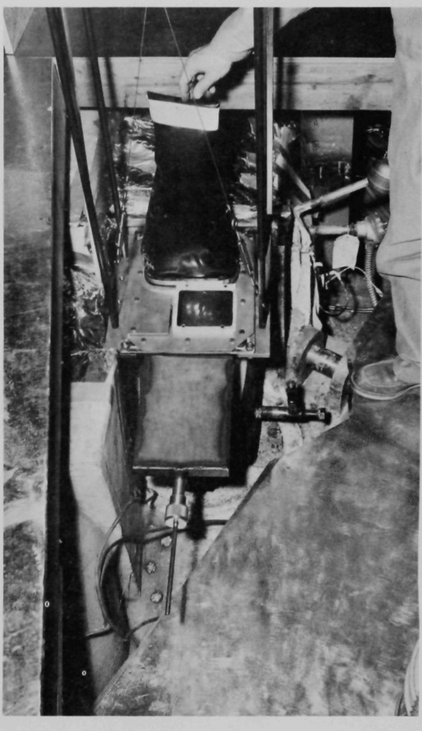


Fig. 11. Access-port Cover Plate with Boot for Periscope. ANL Neg. No. 103-N5910.

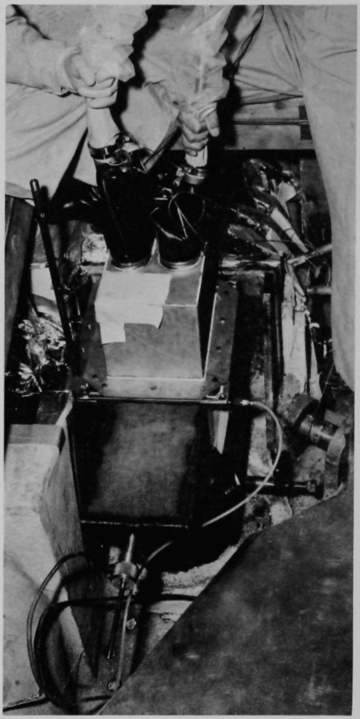


Fig. 12. Access-port Cover Plate with Boot Assembly for TV Camera. ANL Neg. No. 103-N5952.

Extensive use was made of the mockup to check out each unit to be used in the IHX. Modifications to initial designs were defined and detailed procedures developed for the use of each item. Dry runs were made before each use of new equipment.

December 16, 1970

A view of upper clip was obtained with the periscope, using a flashlight for illumination. The upper clip was intact, but some distortion was suspected.

December 17, 1970

A second inspection was made with the periscope, aided by the quartz lamp. It was found that the upper clip was indeed sprung away from the

1-in. evacuation tube and that the lower clip was broken off and missing. Nothing unusual was observed in the diffuser-trough assembly. TV pictures were taken through the periscope.

December 18, 1970

The first penetration was made of the IHX with a TV camera, aided by illumination from the quartz lamp. Initially the focus on this camera could not be adjusted remotely, but had to be set before lowering the camera into the inlet pipe. The effort to coordinate the fixed focus of the TV camera and the independent lighting proved inefficient and time-consuming. Moreover, the heat from the 1500-W quartz lamp applied additional heating to the TV camera, which shortened the time available for viewing.

In spite of focusing difficulties, useful views were obtained of the IHX internal details. These views expanded and verified the observations made with the periscope.

December 23, 1970

The TV camera was modified by EBR-II personnel to include its own lighting system and a remotely adjustable focusing mechanism. A repeat TV examination produced vastly improved results.

Photos were taken from the TV monitor screen. The results are shown in Figs. 13-16.

Fig. 13

Television View of Upper Support Clip. ANL Neg. No. 103-05002.

Fig. 14

Television View Showing Weldment Where Lower Support Clip Was Welded to 12-in. Pipe Wall. ANL Neg. No. 103-05005.

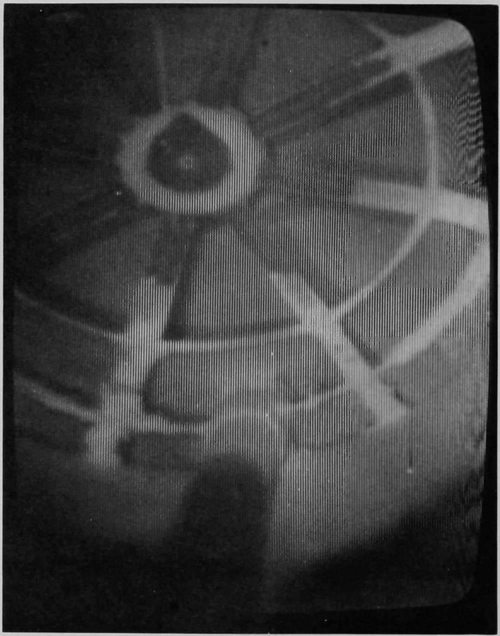


Fig. 15

Television View of Diffuser Troughs and Support Ribs at Lower End of IHX Inlet Pipe. ANL Neg. No. 103-05004.

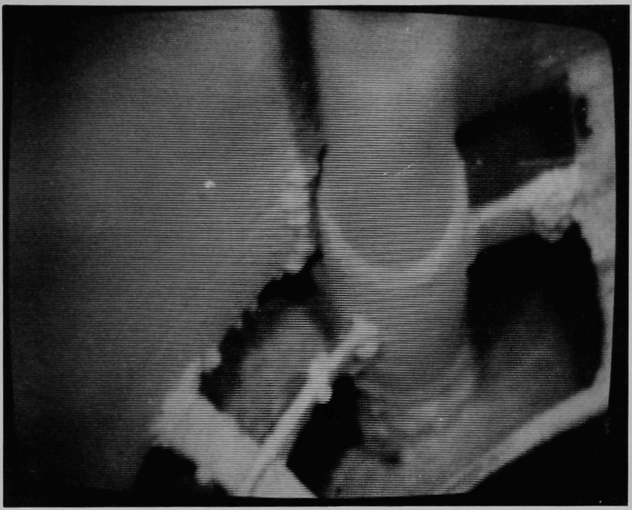


Fig. 16. Television View of Lower End of Evacuation Tube, Showing Fillet Weld to Terminal Piece That Penetrates the Diffuser Troughs. ANL Neg. No. 103-05001.

Figure 13 clearly shows that the upper clip was bent away from the 1-in. evacuation tube. Later investigation established that the tube was free to move within the bent clip and was not held tightly by any mechanism.

Figure 14 shows the remaining portion of the lower clip, essentially the weld portion. The white spots appear to be sodium deposits. A dark band (not shown) on the tube adjacent to the stub of the lower clip appeared to be the mark left by the lower clip before the clip was broken. Figure 15 is an overall view of the diffuser-trough assembly and support ribs. The lower end of the evacuation tube is also shown in this view. The white areas again appear to be sodium deposits. Figure 16 is a closeup of the terminal piece for the evacuation tube.

The evacuation tube appeared to be welded solidly to the terminal piece, and the terminal piece appeared to be properly welded to the diffuser troughs. The troughs did not appear distorted, and the center post appeared intact. The integrity of these joints was later verified in other examinations. This TV examination gave no indication of foreign objects lodged in the diffuser-trough assembly. Foreign objects could, however, have been lodged out of sight around the bends of the troughs. An attempt was made later to look around these troughs for foreign objects. That attempt was only partly successful.

December 30, 1970

An initial gamma-radiation scan of the IHX inlet pipe was made. A G-M tube (maximum range: 200 mR/hr) was used to make a gross gamma measurement, and a NaI(Tl) scintillator-crystal system to record spectral information. The gross scan indicated that the value of gamma radiation equaled or exceeded the 200-mR/hr range of the instrument at locations greater than 12 ft below the access port. The performance of the scintillator indicated that the gamma-radiation intensity exceeded the capability of the measurement system at more than 7 ft below the access port. Plans were formulated for a new scintillator system that would include a shielded container. A more detailed description of the gamma sensors is given in Sect. V.D.

January 4, 1971

The gross gamma scan of the IHX inlet pipe was repeated, using a Jordan Radector with a range of 0-500 R/hr. The results indicated a maximum radiation level of about 230 mR/hr at the level of the primary-sodium exit just above the top of the thermal barrier. The gamma profile, along with significant IHX parts, is shown in Fig. 17. The profile has a one-to-one correlation with the structural elements of the IHX. The peak at the 9-ft level

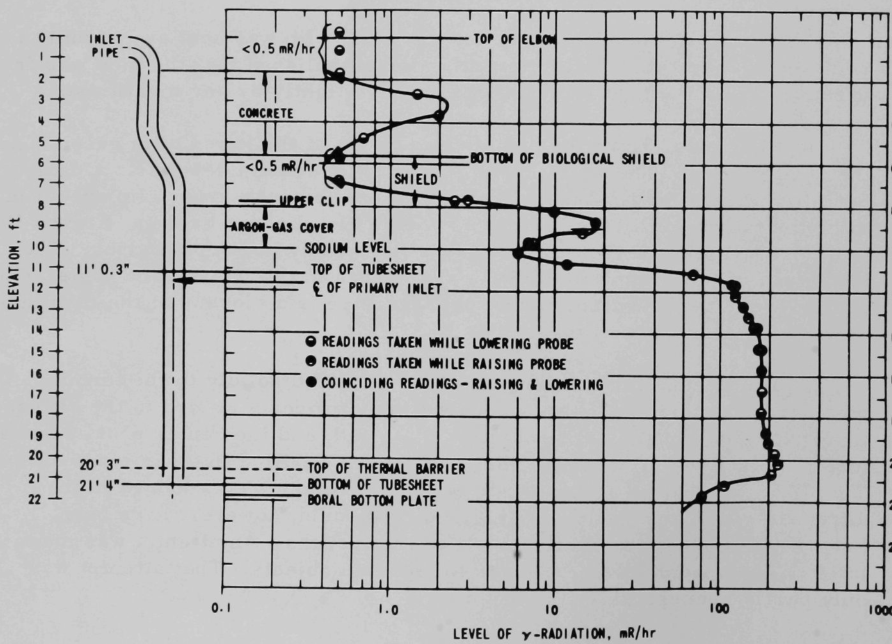


Fig. 17. Results of Scan of EBR-II IHX with Jordan Radector. ANL Neg. No. 103-05811 Rev. 1

corresponds to sodium scale, which may accumulate at the top of the sodium liquid like scum on a bathtub, and has been similarly found on other assemblies removed from the primary tank. The high levels between 12 and 21 ft correspond to the primary-flow portion of the IHX, with the peak appearing at the outlet below the borated shield. The reduction in radiation level at 22 ft corresponds to the reduction in intensity expected behind the shielding at the bottom of the IHX.

January 4, 1971

The IHX mockup was rebuilt to duplicate the condition of the clips as shown by the TV examination. These changes were made to provide proper configuration for checkout of repair tools.

The decision was made to repair the IHX by removing the top clip and the evacuation tube rather than trying to reattach the tube to the inlet-pipe wall. The function of the evacuation tube could be met in the future by installing a pump-out tube as needed.

January 5-9, 1971

Clip-removal tools were checked out in the mockup. It was found possible to bend the clip back and forth and break it off at the weld. The ball-impactor noise generator was also checked out in the mockup. The generator is described in Sect. V.C.

January 11, 1971

The bottom of the IHX was reexamined with the TV camera to check the integrity of the evacuation-tube terminal-piece welds to the diffuser-trough assembly. All welds appeared intact; however, all surfaces were coated with frozen sodium, and a cracked weld would have been difficult to identify.

January 12-13, 1971

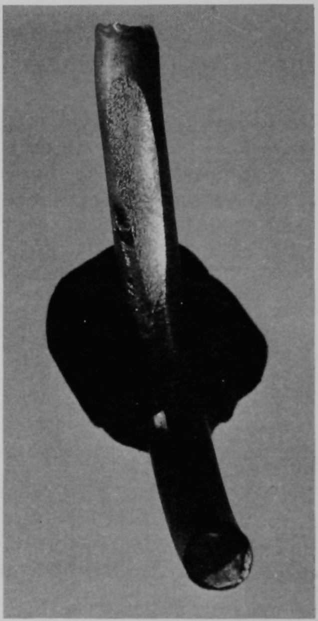
Noise-signature-analysis tests were performed for correlation of earlier noise data and for comparison with any future noise analysis associated with the IHX. The inlet pipe was excited with the noise generator at various levels. The system was also excited by rapping on the evacuation tube with a straight rod. These vibration tests did not excite the low resonant frequencies of either the inlet pipe or the evacuation tube. They did, however, excite the higher-frequency circular resonance of 2.6 kHz of the inlet pipe itself.

January 14, 1971

The upper clip was removed. (The tools used for this task are discussed in Sect. VI.A.) The clip was first partly straightened with a twist tool shaped to engage the end of the clip. The break-off tool was then used to bend the clip back and forth to break it off. The clip was captured in the break-off tool and withdrawn from the inlet pipe.

Figure 18 shows the upper clip after removal. The clip as shown in Fig. 18a is still covered with sodium oxide, while in Fig. 18b it has been cleaned. If one ignores the tool marks, the wear mark made by the 1-in. evacuation tube is apparent. A matching groove was seen on the evacuation tube when it was withdrawn. The weld stump appeared similar to that remaining at the lower-clip location.

a. Support Clip before Cleaning



b. Support Clip after Cleaning

Fig. 18. Photographs of the Removed Upper Support Clip. ANL Neg. Nos. 103-05209 and 103-05213.

January 15, 1971

Collection of vibration data was continued by recording the vibrational response of the system while exciting the evacuation tube from the outside. Without the clip, the evacuation tube oscillated at natural frequencies consistent with conventional analytical calculations. The resonant frequencies observed were compared to the calculated frequencies (see Appendix A, Low Frequency, Case 1). The results of the comparison are given in Table III.

TABLE III. Measured and Calculated Resonant Frequencies of Evacuation Tube without Clips

Measured Values, Hz	Calculated Values, Hz	
	Bottom End Fixed	Bottom End Pinned
3.6	3.56	2.45
9.7	9.8	7.95
19.4	19.3	16.3
30.4	31.6	28.3
49.5	47.5	43.4

Since the measured values correspond more closely to the model with fixed ends than to the model with one pinned end, indications are that the terminal piece was firmly welded as specified.

January 15, 1971

The evacuation tube was cut off just inside the inlet-pipe elbow. The cut was made with a tungsten-inert-gas (TIG) welding torch. The tools used for this operation are shown in Fig. 19. The end of the tube was then cut again with a tube cutter to leave a smooth end. The end of the tube after being cut off is shown in Fig. 20. Several long thin slivers of molten material were left in the evacuation tube from the TIG cutting operation. These slivers were removed on January 18 with wire brushes. One small sliver was lost in the inlet pipe and not recovered.

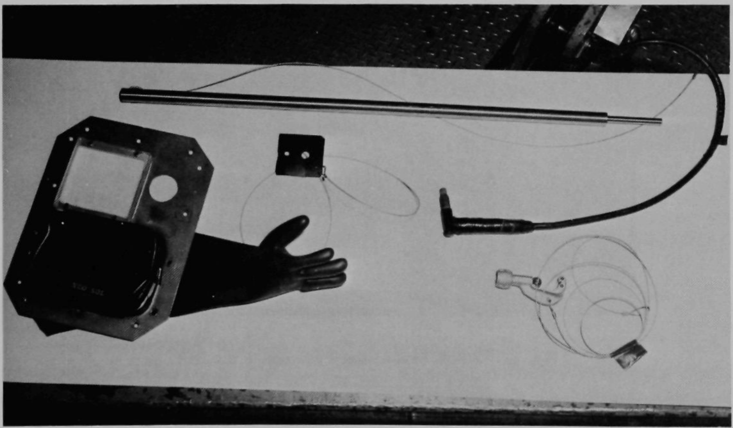


Fig. 19. Tools Used for Cutting Free the Upper End of the Evacuation Tube. ANL Neg. No. 103-05258.

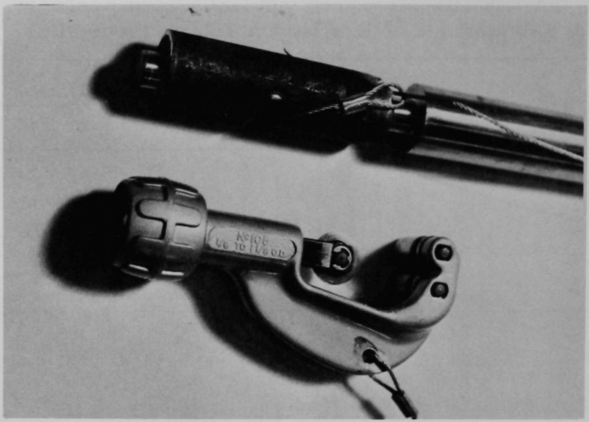


Fig. 20. Removed Upper Piece of Evacuation Tube and Tubing Cutter. ANL Neg. No. 103-05251.

Figure 21 is a view into the IHX inlet pipe showing the cutoff end of the evacuation tube. This picture is taken through the Plexiglas view plate on the access port.

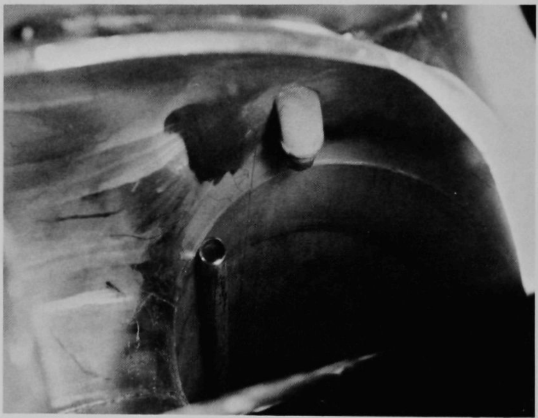


Fig. 21. Cutoff Evacuation Tube inside the IHX Inlet Pipe. ANL Neg. No. 103-05253.

January 19, 1971

An inflatable bladder was placed in the inlet pipe upstream of the access port to stop the flow of cold argon gas. The bladder and tubing are shown in Fig. 22. The argon flow had kept the temperature in the bottom of the IHX at about 180°F, well below the sodium freezing point. With the circulating flow stopped, the temperature rose to about 280°F in 3 hr as determined by a thermocouple. The increased temperature melted the sodium still clinging to the trough, trough supports, and weld joints, so any loose weld connections could be seen. The TV camera was inserted to the bottom region, and the evacuation tube was vigorously shaken from the top. Of particular interest was the socket weld of the evacuation tube to its terminal piece. There was no evidence of looseness.

A hook was then used to pull firmly on each of the trough-support ribs. Each felt solid and appeared solid in the TV view. The hook is shown in Fig. 23.

Fig. 22. Inflatable Bladder Used to Stop Circulation of Argon through the IHX. ANL Neg. No. 103-05269.

Fig. 23. Hook Tool Used to Pull on the Diffuser-trough Support Ribs. ANL Neg. No. 103-05271.

January 26, 1971

A hydraulic rod and bar cutter was received. This tool was an H. K. Porter Model H118, modified for use in cutting the lower end of the evacuation tube. The tool was operated with high-pressure argon. (See Sect. VI.B for details of the cutter.) The technique for support and application of this tool was worked out in the mockup. It was found that a push rod was needed to force the cutoff jaws of the tool behind the evacuation tube in order to make the cut close to the terminal piece. A low-pressure squeezing action (~200 psig) was required to flatten the tube and gain clearance to lower the cutter to its final cutting position. The TV system was used to aid in locating the tool on the tube and to view the cutting action. A successful cut of the mockup stainless steel tube was made using 2000-psig argon.

January 27, 1971

The evacuation tube in the IHX was cut off at the lower end and removed. The technique developed in the mockup was applied successfully. Five low-pressure squeezes (~200 psig) were applied to flatten the tube in order to lower the tool to cutoff position. A final application of 2000 psig cut the tube. The TV system was used to guide the operation as in the mockup.

The remaining stub of the evacuation tube measured $5\frac{7}{8}$ in. above the socket weld on the terminal piece.

The ends of the tube at the break were observed to be squeezed tightly together, but the material was not mechanically joined as would be the case with a pinch-off made similarly with copper.

Figure 24a shows the remaining stub, and Figs. 24b-d show the removed tube. The photo of the bottom of the removed tube (Fig. 24b) shows the five flattening spots made before the final cut.

The tube showed wear spots at numerous places along its length. The most prominent rub marks, caused by the upper clip and the weld on the 12-in. pipe just above the clip, are shown in Figs. 24c and 24d.

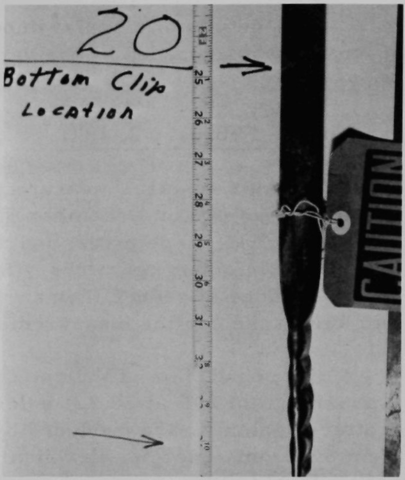
The depth of the wear mark made by the clip was about 0.025 in., and that made by the inlet-pipe weld was 0.029 in. The evacuation tube was activated only at the lower end of its length; the maximum gamma measurement was 1-2 mR/hr at contact.

January 28, 1971

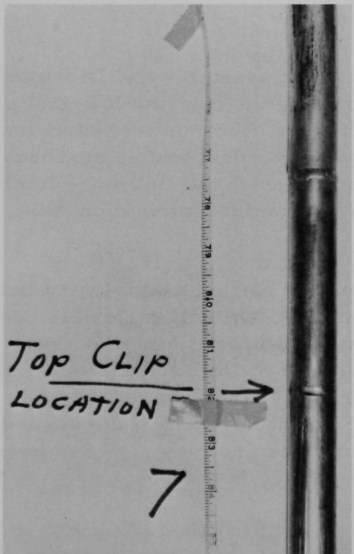
The final portion of the noise-signature analysis was made. The ball-impact tool was rebuilt in a straight configuration and positioned on both the first and second diffuser troughs and the center post. The trough angles and the sodium remaining on the trough surfaces prevented good mechanical contact for force transmission from the ball, and the noise transmitted from the generator to the system was not repeatable. With the center-post configuration, however, the noise was repeatable because good contact was made.

The major resonances that were recorded in both cases were the higher-frequency circular modes.

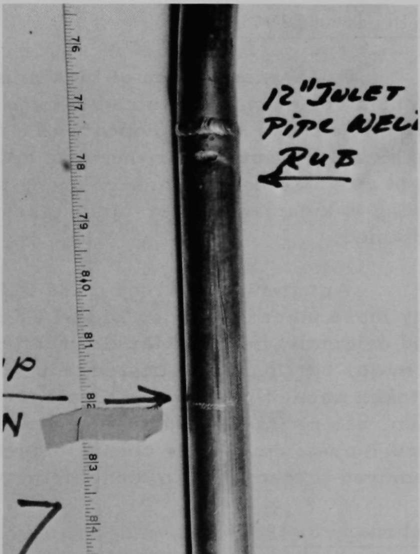
a. Remaining Stub after Removal of Evacuation Tube



b. Bottom of Removed Tube



c. Evacuation Tube with Rub Mark from Upper Clip



d. Evacuation Tube with Rub Mark from Weld on 12-in. Pipe

Fig. 24. IHX Evacuation Tube after Removal. ANL Neg. Nos. 103-P5162, 103-05370, 103-05379, and 103-05378.

The details of circular-mode calculation and the observed natural resonances as recorded by the various accelerometers are described in Appendix A.

January 29–February 2, 1971

Gamma spectral measurements were made in the inlet pipe similarly to those attempted on December 30, 1970. The detector had been rebuilt with a new NaI(Tl) detector, and the detector was surrounded by $1\frac{3}{4}$ in. of lead in an aluminum container. (See Sect. V.D for detector details.) The lead was added to reduce the gamma intensity, which had saturated the system during the earlier measurements.

The dead time of the detector was reduced to tolerable levels (a maximum of 25% at 20.5 ft below the access port); however, the Compton-scattered gamma rays produced by the lead shield produced a broad spectrum of gamma energies in which identification of specific energies was nearly impossible. A typical example of the multichannel record and a discussion of the results are given in Appendix C. In summary, broad humps and slope changes characteristic of the gamma spectra of the radionuclides ^{54}Mn, ^{60}Co, and ^{22}Na were tentatively identified.

February 5, 1971

A TV examination of the diffuser-trough assembly and IHX inlet-plenum region was attempted in hope of locating the missing lower clip. The TV camera was provided with a flexible 4-ft fiber-optics extension lens. A light source for the fiber optics was provided, and an auxiliary light was also used. Perhaps owing to insufficient light, but more likely owing to a damaged fiber-optics assembly, no useful information was obtained.

An attempt was then made to "rake" the baffle assembly and bring any loose pieces into view of the TV camera. A tool with a flexible conduit end originally designed for clip retrieval was used for raking the area. A major portion of the center trough, about half of the second trough, and a token amount of the third trough were "raked" in the procedure. The sodium was not melted during the operation, and the clip, if in the diffuser-trough area, could have been "soldered" in place and may not have been removed if touched. No loose items were located in the search.

February 8, 1971

A final TV view of the diffuser-trough assembly and inlet-pipe area was put on videotape for record purposes. The decision was made to terminate further examination and proceed to close the IHX and return to operation.

February 9, 1971

The cutout section of the inlet elbow with Y-ring insert was positioned in the elbow opening, and the access-port assembly was removed.

The root pass of the elbow-section weld was then made. A radiograph of this weld pass revealed three defects: (a) the consumable insert was not completely fused over a 1/8-in. length, (b) there was one large low-density pore located by itself near a corner, and (c) two small pores existed about 1/4 in. apart. The first two defects had to be removed, but the third was within acceptance standards of Sect. III of the ASME Boiler Code.

The welding procedure is covered in detail in Sect. IV.

February 10, 1971

The required repair of the two defects in the root pass was accomplished. An attempt was made to remove the third minor defect. One additional layer of weld metal (two passes) was completed over the root pass. Radiographic examination revealed that weld repair was successful, except for the third minor (within Code) defect.

The evacuation-tube penetration of the 12-in. elbow was capped.

February 11, 1971

Welding of the patch in the 12-in. elbow was completed. A secondary containment was welded in place over the evacuation-tube penetration through the 12-in. elbow.

Final radiographic examination of the completed weld showed acceptable quality.

February 12, 1971

Electrical heaters were installed on the inlet pipe and elbow. Reinsulation of the piping was initiated.

March 3, 1971

The power plant began operation, and the first postrepair noise data were obtained. No unusual audible noise was present during any operation to 62.5 MW.

March 8, 1971

Noise recordings indicated very quiet operation with no evidence of the excessive amplitudes of resonant frequencies caused by the evacuation tube on November 14, 1970. The remaining resonant frequencies at about 2.6 and 2.7 kHz are characteristic of the circular frequencies of the inlet pipe and are present in both the before and after noise spectra in approximately equal magnitudes. Figure A.8 (in Appendix A) demonstrates the change in signature after completion of the repair.

IV. OPENING, ENTRY, AND CLOSURE OF THE IHX

Two methods of obtaining access for examination of the inlet portion of the IHX were considered:

1. Remove the 12-in. inlet elbow.
2. Cut an access hole in the top (outside surface) of the 12-in. inlet elbow.

Removal of the 12-in. elbow would have provided a larger access hole, but would have been much more difficult in removal and replacement because access to both elbow weld joints is extremely limited. Cutting an access hole in the inlet elbow was judged to be the most practical method for entry into the IHX. Desirable features of this method were:

1. Access to the work area was excellent.
2. The argon atmosphere could easily be maintained by the attachment of a simple glovebox-type assembly.
3. A hole large enough for all anticipated inspections and repair operations could be provided.
4. Cutting of the access hole could be accomplished relatively fast.
5. Reclosure of the elbow by welding did not appear to be particularly difficult.
6. The closure weld could be easily examined by radiography.
7. This entry method was essentially identical to that successfully used by APDA at the Enrico Fermi Atomic Power Plant during reactor repair operations described in Ref. 4.

To ensure that the cutting and subsequent rewelding of the inlet elbow could be satisfactorily accomplished, the operations were first performed on a test elbow. The elbow used for this operation was different in two respects from the IHX elbow. The IHX elbow was Schedule 20 and was fabricated from halves by making two seam welds: one at the inside radius, the other at the outside radius. Twelve-inch Schedule-20 elbows can no longer be procured without special fabrication. The elbow used for the cutting and welding qualification was a 12-in. Schedule 40 S conforming to ASTM A403 Grade WP 304L. The difference in the elbows was not important for the intended purpose; however, it proved to be more difficult to perform the cutting and welding on the test elbow because of the greater wall thickness.

All cutting and welding operations on both the test and IHX inlet elbows were performed by the same welder. Procedure and performance qualification was accomplished in accordance with ASME Boiler and Pressure Vessel Code, Sect. IX, Welding Qualifications.

Cutting of the access hole (6 x 9-in. projected size) was accomplished by hand grinding, preparing the joint for rewelding as the cut was made. Grinding dust was continuously removed by vacuuming to maintain cleanliness. When the test elbow was cut, the debris that entered the pipe was carefully collected and examined. The debris was a fine dust consisting mainly of stainless steel and had a total weight of 0.42 g. As the cut was made, repositioning clips were welded to the cutout section.

The initial attempt to reweld the patch in the test elbow was not successful. Difficulty was experienced because the removed section was distorted by weld-metal shrinkage. The positioning clips as shown in Fig. 25 were not strong enough to hold the patch in place. Because of this difficulty, the technique for cutting and rewelding was modified as follows:

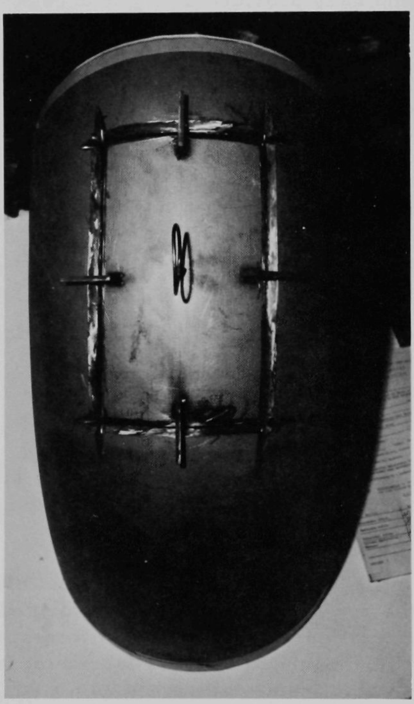


Fig. 25. First Elbow-weld Specimen, Showing Lightweight Positioning Clips. ANL Neg. No. 103-N5788.

1. The positioning clips were made stronger, and their number was increased from four to six.

2. The weld-joint design was modified to utilize a Y-ring-type consumable insert. The original joint was an open butt.

3. Rewelding was accomplished by a sequenced, detailed procedure that minimized problems associated with weld shrinkage.

With the above changes to the cutting and welding procedures, the welding was accomplished on the test elbow without difficulty. Figure 26 shows the test elbow with the positioning clips and consumable insert in place ready for welding of the root pass. The completed weld was radiographed through the opposite wall of the elbow using an iridium-192 source. The radiograph and also a liquid-penetrant examination of each weld pass verified that the test weld was acceptable. This operation confirmed that it was possible to enter the IHX by the method proposed and later accomplish a satisfactory closure.

On December 14, 1970, the access hole was cut in the IHX inlet elbow. Figures 27 and 28 show the locations and geometry of the cuts. The

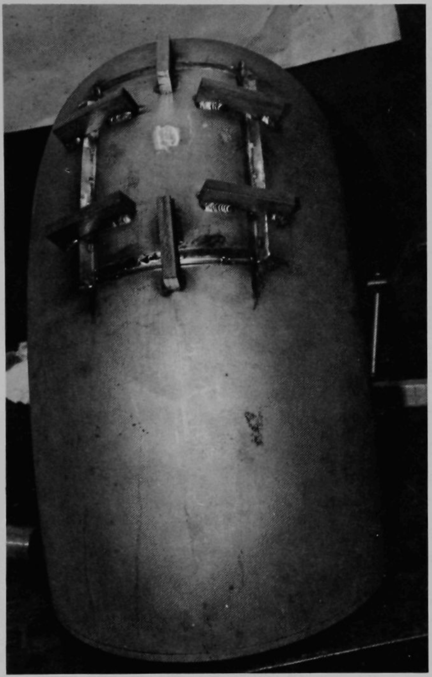


Fig. 26

Modified Elbow-weld Specimen, Showing Consumable Insert and Heavyweight Positioning Clips. ANL Neg. No. 103-N5842.

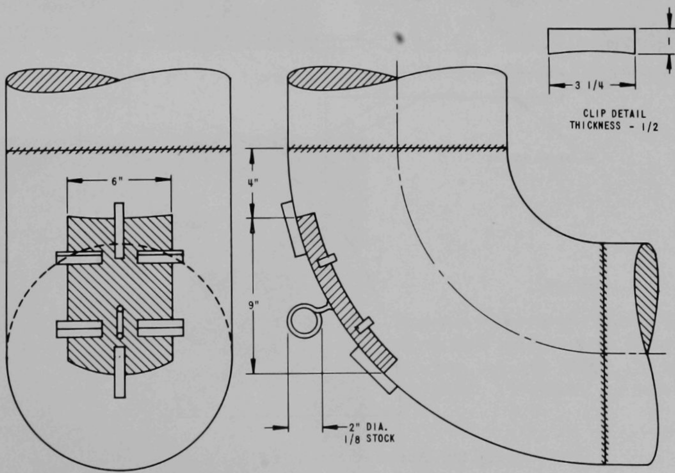


Fig. 27. Dimensions of Cutout Section on 12-in. Elbow

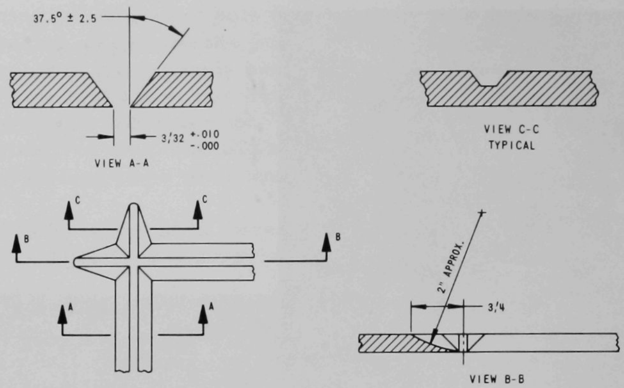


Fig. 28. Details of Weld Joint for Use with Consumable Insert (Y-ring)

entire operation was accomplished without difficulty in about 10 hr. An access port as shown in Fig. 29 was installed over the cutout section and was sealed to the elbow with RTV silicone rubber. Figure 30 is a sequence of photographs showing the cutting operation and the installation of the access port. The port was designed with a sliding gate valve and a flanged closure (11 x 8-in. inside dimensions) to provide means for entering and viewing the interior of the inlet pipe while maintaining the inert argon atmosphere within the system. Half-inch Swagelok connections were installed on the access port above and below the sliding gate to provide means for venting, purging, and monitoring system pressure as required.

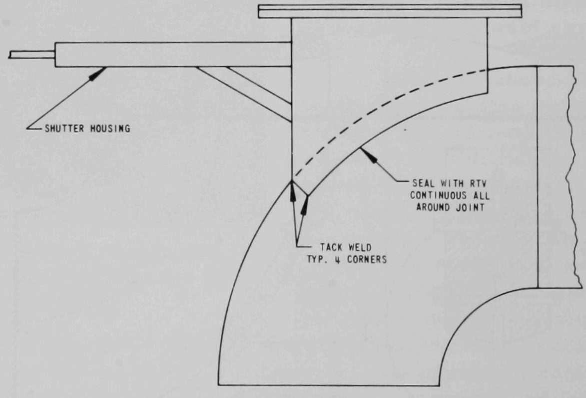
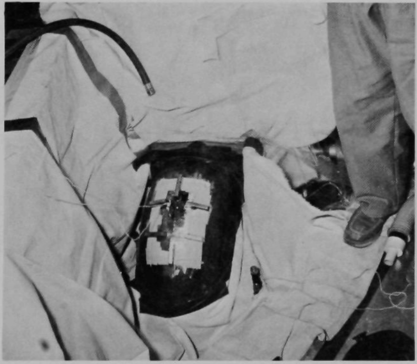


Fig. 29. Access Port on Inlet Elbow of IHX

a. Vacuuming of Grinding Dust during Cutting Operation

b. Cutting of Access Hole with Grinding Tool

c. Grinding near Completion with Gaps Taped Shut



d. Grinding Completed with Cutout Section Taped in Place

e. Access Port Installed on Inlet Elbow

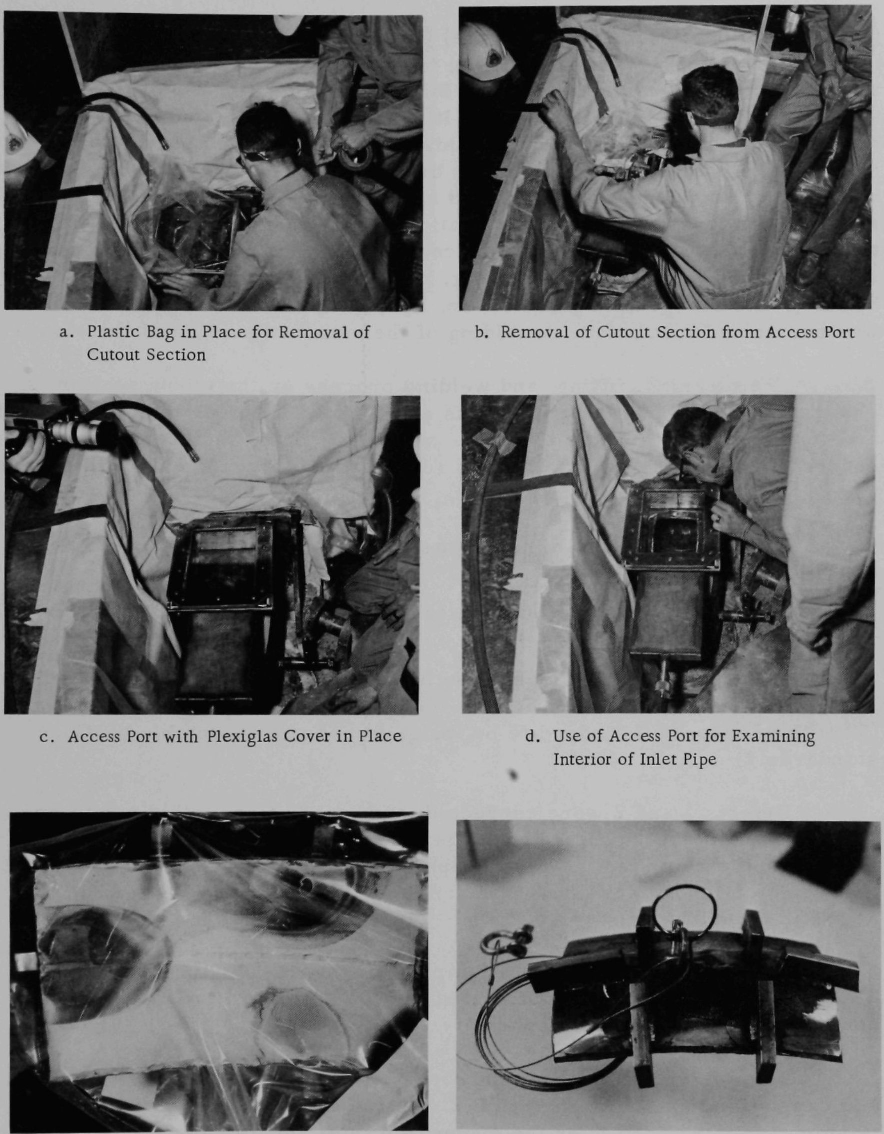
Fig. 30

Sequence of Photographs Showing Cutting of Access Hole and Installation of Access Port. ANL Neg. Nos. 103-N5869, 103-N5866, 103-N5867, 103-N5872, and 103-N5868.

Figure 31 shows the access port installed on the IHX inlet elbow with the cutout section ready for removal. Figure 32 is a sequence of photographs showing (a and b) removal of the cutout section through the access port, (c) the access port with shutter closed, (d) the view through a Plexiglas cover bolted on the access port, and (e and f) the section removed from the elbow. The photograph (Fig. 32e) of the underside of the section shows that the surface was completely wetted by the sodium.

The IHX inlet elbow was reclosed without difficulty using the procedure developed on the test elbow (see Appendix B). In preparation for welding, the removed section was trial-fitted into the elbow, and a measurement was made of the amount of metal that had to be removed to establish the proper weld-joint gap for insertion of the consumable insert (Y-ring). The edge of the removed section was ground back, and the consumable insert was tack-welded to it. The elbow portion of the weld joint needed no additional preparation except deburring and cleaning. Deburring was accomplished as soon as the patch was removed by first inserting a catch pan

Fig. 31. Access Port Installed on Inlet Elbow with Cutout Section Ready for Removal. ANL Neg. No. 103-N5873.



a. Plastic Bag in Place for Removal of Cutout Section

b. Removal of Cutout Section from Access Port

c. Access Port with Plexiglas Cover in Place

d. Use of Access Port for Examining Interior of Inlet Pipe

e. Bottom View of Cutout Section

f. Top View of Cutout Section

Fig. 32. Sequence of Photographs Showing Removal of Cutout Section and Viewing through Access Port. ANL Neg. Nos. 103-N5896, 103-N5900, 103-N5899, 103-N5898, 103-N5897, and 103-N5908.

(machined to fit the inside curvature) inside the elbow and then filing the edge as necessary. Very little filing was required; the deburring operation was completed in less than 10 min. Since the inside surface of the elbow was completely coated with sodium, it was necessary to clean back from the weld edge for several inches. This was accomplished by a combination of wiping with a damp cloth and wire brushing. Pressurized argon (~60 psig) was used to drive the air motor used in the brushing operation. Figure 33a shows the wire-brush cleaning operation being accomplished by reaching through a plastic bag sealed to the access port. Note that a window is installed in the plastic bag for viewing, and that the bag is ballooned outward by the positive argon pressure (~1 in. H_2O) in the system. Final cleaning was performed just before rewelding of the removed section of the elbow.

The cleaning, fitting, and welding process on the elbow section is shown in the sequence of photographs of Fig. 33. The root pass of the weld and removal of the support clips was accomplished by the sequenced procedure included in Appendix B. The root pass was examined by radiography, and the following defects were found:

1. The consumable insert was not completely fused over a length of about 1/8 in. at one location.

2. One large pore (bubble), about 1/8 in. in diameter, existed in the root pass.

3. Two pores of fine size with spacing of about 1/4 in. existed.

(This third defect was judged to be insignificant and acceptable by Code standards.*)

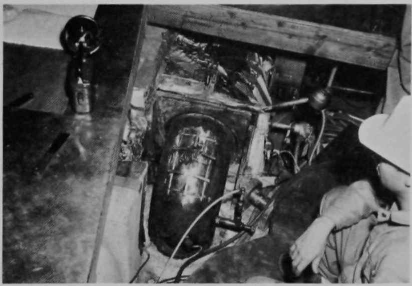
Defects 1 and 2 were corrected, and an additional weld pass was applied over the root pass. Figure 34 shows the weld at this time with liquid penetrant applied. A radiograph of the weld at this point verified that defects 1 and 2 were corrected and that the root pass was now of acceptable quality.

The elbow weld was then completed using the TIG process with Type 308L stainless steel filler wire. A third and final radiograph of the completed weld verified acceptability.

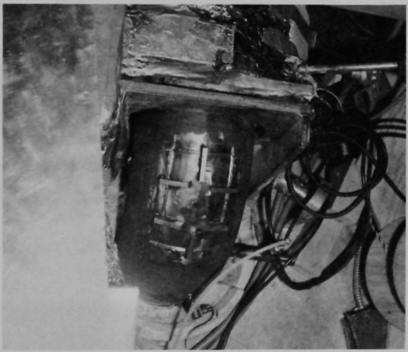
The stub of the evacuation tube outside the inlet elbow was shortened and cap-welded as shown in Fig. B.2. As the figure shows, secondary containment was provided over the evacuation tube where it penetrated the inlet elbow. Figure 33f shows the inlet elbow with all welding completed and ready for insulation.

*Paragraph N-624 of Sect. III, Nuclear Vessels, ASME Boiler and Pressure Vessel Code.

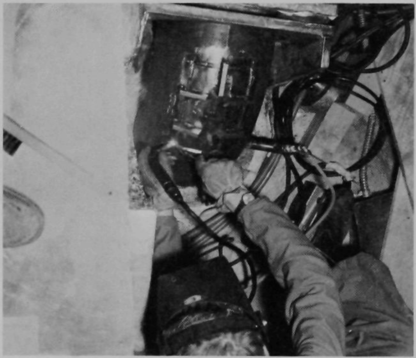
a. Brush Cleaning and Deburring of Inside of Inlet Elbow



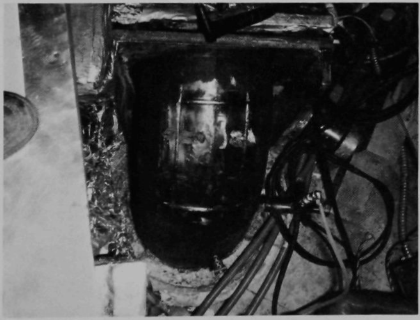
b. Cutout Section in Place for Welding of Root Pass



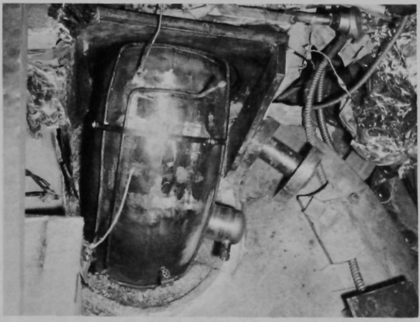
c. Cutout Section in Place with Root-pass Welding Partially Completed



d. Welding of Root Pass



e. Completed Root Pass



f. Completed Weld of Cutout Section

Fig. 33. Sequence of Photographs Showing Deburring at Elbow and Welding of Cutout Section. ANL Neg. Nos. 103-05574, 103-05571, 103-05634, 103-05633, 103-05581, and 103-05639.

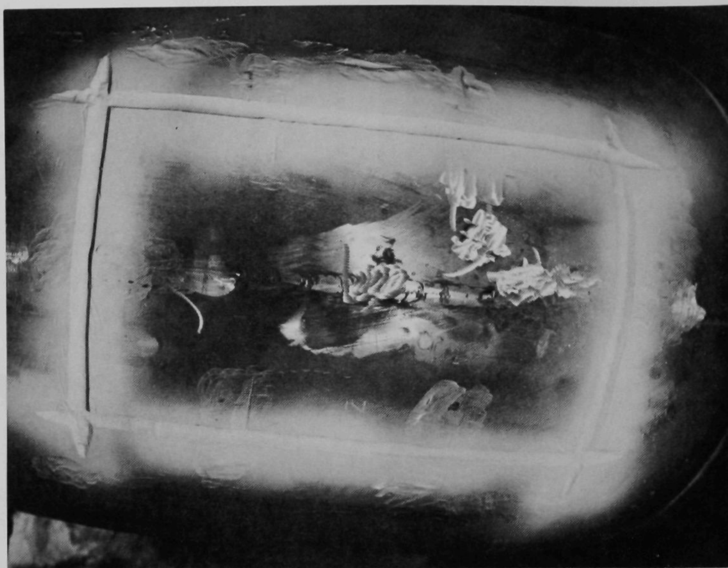


Fig. 34. Inlet-elbow Closure Weld after Second Pass, with Liquid Penetrant Applied. ANL Neg. No. 103-05628.

V. INVESTIGATIVE EQUIPMENT

A. Periscope

A detailed visual inspection of the complete interior of the IHX inlet pipe was an essential requirement of the investigative program. Two versions of a closed-circuit TV system were used along with a periscope viewer. A $1\frac{5}{8}$-in. borescope used for viewing during the Fermi repair[4] was also secured on loan and checked out but not used. The periscope was used in the early inspections before the TV system was fully developed. The first gross indication of the source of noise was obtained by use of the periscope. All subsequent detailed examinations of IHX components and the viewing for repair were supplied by the closed-circuit TV equipment.

Figure 35 shows the periscope and Fig. 36 shows its placement in the inlet pipe. The design used a 3-in.-dia aluminum tube with a Plexiglas viewing port at one end and a dual mirror arrangement at the other. One of the mirrors could be removed to allow right-angle viewing. The mirrors were 1/8-in. mirrored brass stock and were secured to the end of the aluminum tubing by the use of studs and staked machine nuts. Every effort was made on all equipment inserted in the IHX to ensure that no assemblies or parts could be dropped in the IHX. Liberal use was made of safety lanyards, staking, safety wire, and locknuts for this purpose.

Fig. 35. Periscope Shown Ready for Insertion into Inlet Pipe. ANL Neg. No. 103-N5913.

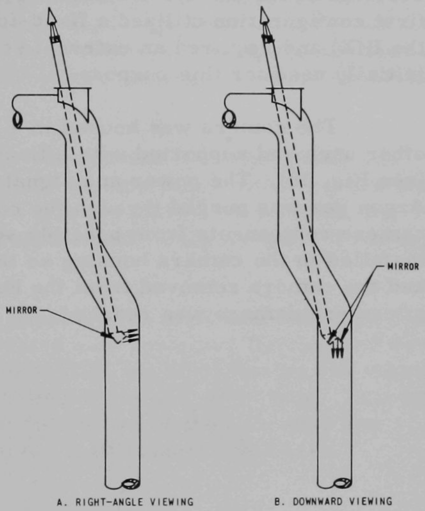


Fig. 36. Diagram Showing Typical Viewing with Periscope in IHX Inlet Pipe

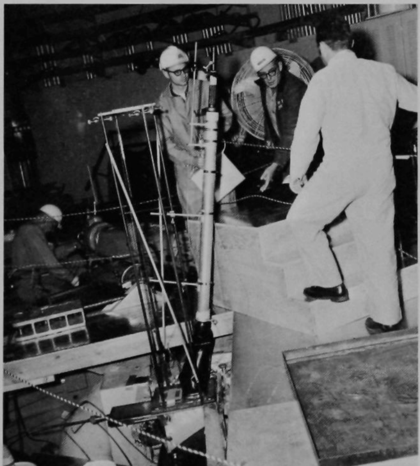


Fig. 37. Clamping Arrangement for Holding Periscope. ANL Neg. No. 103-N5920.

The periscope was held in place on the access port by various clamping arrangements illustrated in Fig. 37. Steady support was required in order to obtain a satisfactory examination. Lighting to aid in periscopic examination was provided by flashlights shining through the aluminum periscope tube and by use of the quartz lamp described in Sect. V.E. The flashlight supplied sufficient light to identify the condition of the top clip, and the quartz lamp supplied interior lighting, which permitted observation of the bottom region.

B. Closed-circuit Television

Closed-circuit TV (Concord Model MTC-10) was used in this examination and repair with good results. Auxiliary equipment was developed that provided closeup detailed visual records of all points of concern throughout the program. Two basic versions of the TV system were used to obtain the required result. The first configuration utilized a fixed-focus camera (manually adjusted outside the IHX) and required an external source of light. The quartz lamp was initially used for this purpose.

The camera was housed in a cast-aluminum cylinder adapted from other uses and supported with a flexible hose and a light stainless steel tube (see Fig. 38). The power and signal cables were contained within the hose. Argon gas was purged through the camera for cooling and protection of camera components from possible sodium interaction. A thermocouple was installed in the camera housing so that the temperature could be monitored and the camera removed from the hot environment before the threshold of camera damage was reached.

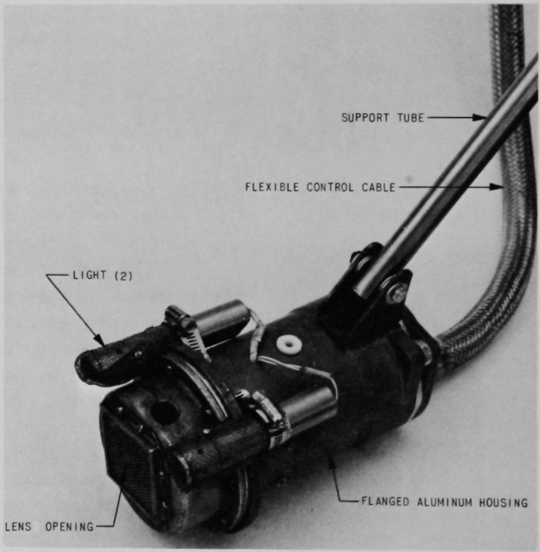


Fig. 38. First Model of TV Camera Support after Modification to Provide Own Lighting. ANL Neg. No. 103-P5435.

The primary-tank sodium temperature was approximately 300°F throughout the investigation and repair period. Since the entire secondary sodium system had been drained, the argon cover gas was provided a natural convection path which brought cool argon (50°F) down through the inlet pipe. The argon temperature rose to about 180°F at the bottom of the inlet pipe. This comparatively low temperature, plus the argon purge in the camera itself, prolonged the temperature rise in the camera so that viewing periods of 15-20 min at the bottom of the inlet pipe were possible.

The camera was positioned by hand in the inlet pipe by twisting the control tubing and adjusting the relative heights of the two tubes, which were attached to different places on the camera housing. The light was also positioned by hand. The independence of the focus, direction of camera, and light position presented a difficult coordination problem for the equipment operators, and only modest success was obtained in scanning the inside of the inlet pipe.

This first TV system was modified to provide its own lighting and remote focusing. The remote focusing was accomplished with a reversible dc motor connected to the lens through a friction drive. As a result, the coordination problem was considerably simplified. This modified TV housing is shown in Fig. 38.

A second identical camera was housed in an improved housing. This unit, shown in Figs. 39 and 40, incorporated self-contained lighting and remote focusing. The tilt-control cable along with all other wiring and tubing passed through a single 1-in.-dia, 25-ft-long stainless steel tube. This tube was flexible enough to negotiate the two 30° elbows of the inlet pipe and allowed the camera to be lowered close to the diffuser-trough area.

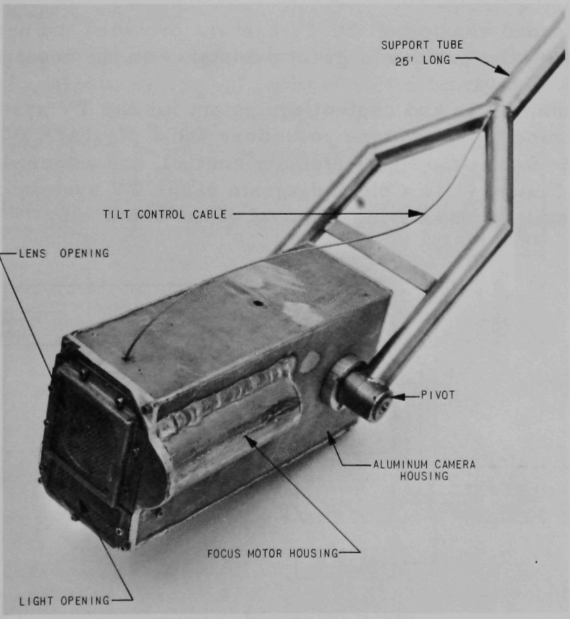


Fig. 39. Second Model of TV Camera Support.
ANL Neg. No. 103-P5436.

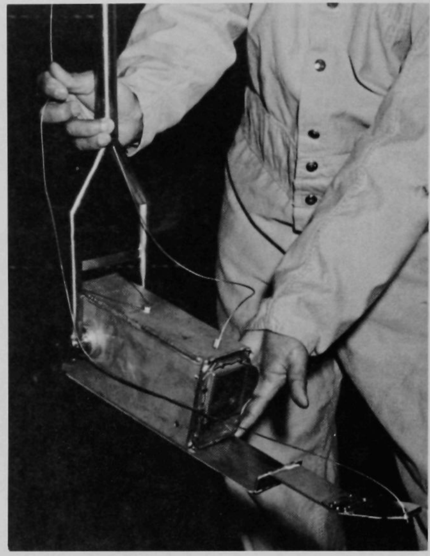


Fig. 40

Second Model of TV Camera.
ANL Neg. No. 103-05125

The second version of the TV camera provided the best observation of the IHX internals and was of great assistance in the repair effort.

The monitoring and control equipment for the TV system consisted of two visual monitors, two tape recorders and a playback system, the drive for the remote focus, the light-intensity control, and a thermocouple-readout instrument. Figure 41 is a block diagram of the TV system. Figure 42 shows the system in use during removal of the upper clip.

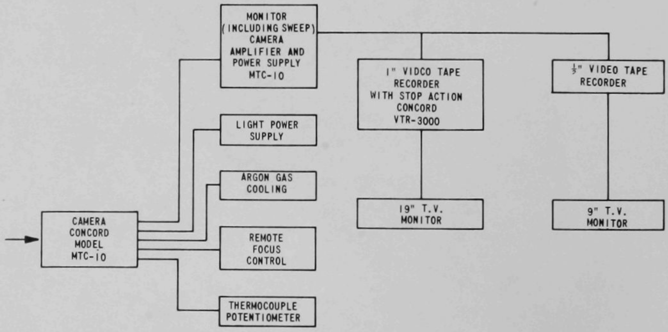


Fig. 41. Diagram of TV System

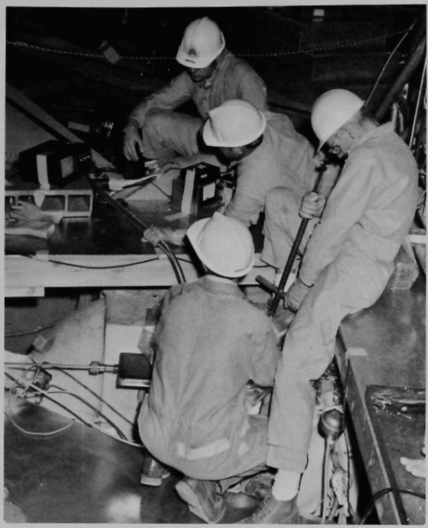


Fig. 42

Television Monitoring of Removal of Upper Clip. ANL Neg. No. 103-05235.

C. Noise-generator System

Noise signatures of the IHX were taken with the transducers and recording and analysis equipment outlined in the block diagram in Fig. 43.

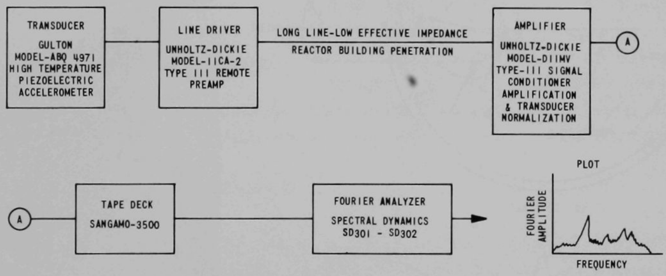


Fig. 43. Diagram of Vibration-analysis System

Accelerometers were mounted as shown in Fig. 44 on the inlet pipe, the outlet pipe, and the IHX flange. A typical accelerometer and mount are shown in Fig. 45.

Noise analyses were conducted with different heat-exchanger conditions:

1. At the time the original noise appeared, and the primary and secondary systems were still operational, the noise was analyzed at various primary and secondary flow rates.

2. With the IHX drained, the ball impactor was used at several places along the inside wall of the inlet pipe. The impactor, shown in Fig. 46, allowed the ball to be released from the same height each time the magnet was pulled through the release point, thus generating a repeatable impact against the IHX wall. The data obtained allowed examination of the longitudinal and circumferential vibrational modes of the inlet pipe and the modes of the evacuation tube.

3. The ball impactor was modified to be made straight so that the impact could be made on the IHX diffuser-trough center post and on the insides of the first and second troughs.

4. After the clip was removed but the evacuation tube was still anchored at the top and bottom, the tube was set in vibration by simply pounding on the external evacuation-tube fitting and observing the resultant tube vibration.

5. After repair was completed and the IHX returned to operation, step 1 was repeated.

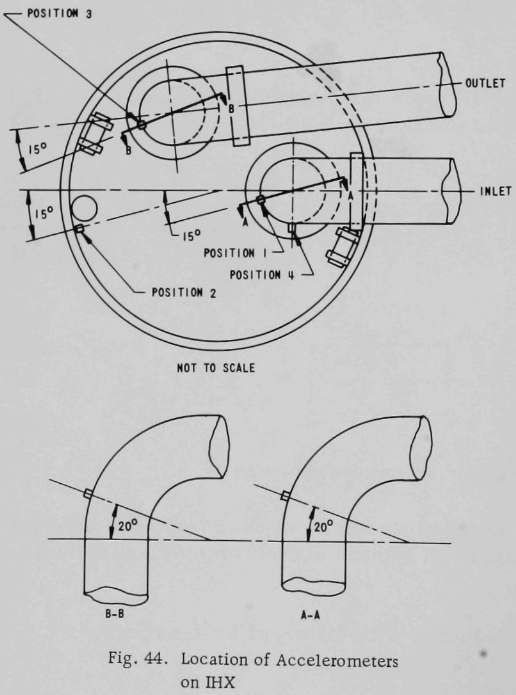


Fig. 44. Location of Accelerometers on IHX

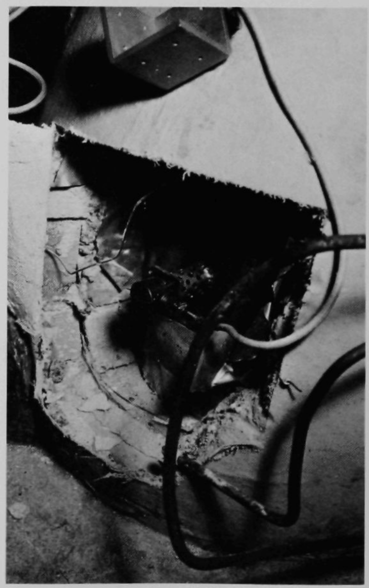


Fig. 45. Accelerometer Mounted on Outlet Elbow of IHX. ANL Neg. No. 103-05630.

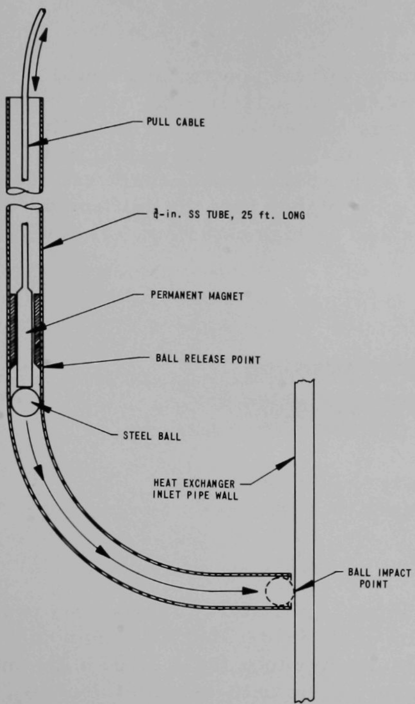


Fig. 46. Ball Impactor for Noise Generation

D. Equipment for Measuring Gamma Radiation

Measurements were made of the intensity and spectra of gamma radiation within the inlet pipe of the IHX. The purpose was to determine as far as possible the location, magnitude, and nature of radionuclides deposited on the primary side of the IHX. This information could aid in an understanding of migration of primary-tank nuclides as well as aid in preparation for future IHX repair if it became necessary. Four separate sensor configurations were used on four separate scans with varying degrees of success. These scans and the equipment used were as follows:

1. First Overall Survey

A standard G-M tube in a $2\frac{1}{2}$-in.-OD, $12\frac{1}{2}$-in.-long stainless steel can was used (see Fig. 47). The tube and control unit was a Ludlum Model 14A with range of 0-200 mR/hr. This assembly and the three other units were suspended on a stainless steel wire-braid hose. The data were satisfactory with this unit to a depth within the IHX of about 12 ft, where levels exceeding 200 mR/hr were encountered.

2. Second Overall Survey

A Jordan Radector ion-chamber probe (range 0-500 R) was substituted for the Ludlum G-M unit, and the overall survey was repeated. The results were satisfactory; they repeated the earlier data and easily covered the range to a maximum of 230 mR/hr. Figure 17 presents the results of this survey. Note that the radiation level follows the significant changes in IHX configuration.

Fig. 47

Stainless Steel Can for Standard G-M Tube. ANL Neg. No. 103-05053.

3. First Spectral Examination

The first attempt at determining gamma spectra and hence determining contaminating species was made with a $1\frac{1}{2}$-in.-OD, 1-in.-high NaI(Tl) crystal (Harshaw Co.). The unit was housed with its preamplifier and photomultiplier tube in a 4-in.-OD, $20\frac{1}{2}$-in.-high stainless steel can (see Fig. 48). The readout was analyzed with a 512-channel analyzer. The gamma levels encountered were considerably higher than the unit could handle. The dead time of the system reached as high as 88% at 9 ft, and no further data were collected.

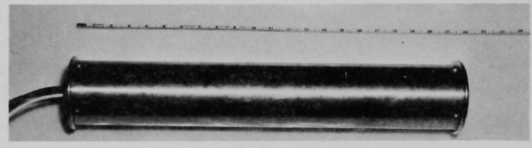


Fig. 48. Stainless Steel Can for Gamma-spectra Detector. ANL Neg. No. 103-05055.

4. Second Spectral Examination

A new Harshaw $1\frac{1}{8}$-in.-OD, 1-in.-high NaI(Tl) crystal was procured and installed in a 6-in.-dia, $17\frac{3}{4}$-in.-high, lead-filled aluminum container (see Fig. 49). The crystal, photomultiplier tube (RCA C70136E), and preamplifier were installed in the container. This unit, as with the other three sensor configurations, contained a thermocouple for temperature observation and an argon supply line for gas cooling of the crystal and other sensor parts.

Fig. 49. Gamma-spectra Detector and Lead-lined Container. ANL Neg. No. 103-05285.

The lead provided sufficient shielding to reduce the system dead time to a maximum of 25%. The lead also caused badly degraded gamma rays from Compton-effect interactions to appear at the crystal. The smoothed energy spectrum therefore masked any prominent and identifiable energy peaks. The configuration and test were not considered satisfactory.

E. High-intensity Quartz Lamp

A separate light source was required for viewing devices not already equipped with lighting. A quartz lamp was adapted for use with the periscope viewer and the first version of the TV system. The lamp assembly was adapted from existing portions of the "Reactor Lower Vessel Lighting Assembly" (Dwg No. 6XN-7520-E) used in the Enrico Fermi Atomic Power Plant during examination and repair operations in 1966-1968 by Atomic Power Development Associates, Inc. (APDA), of Detroit, Michigan.

The assembly was built around a 1500-W, 240-V quartz lamp (Cat. No. Q1500 T-3/CL, GE Co.). The lamp was protected with a 1-in.-dia quartz lens and these items were then supported in a $1\frac{5}{8}$-in.-dia screened stainless steel tube and reflector assembly. This diameter extended for approximately 5 ft to an adapter which reduced to a 3/8-in.-dia, 20-ft-long stainless steel tube. The 3/8-in. tube contained the power cord and argon purging gas, which purged the space between the lamp and the lens to keep sodium vapor away from the quartz. The APDA experience showed that sodium vapor in contact with hot quartz tends to cloud the quartz.

The lower 18 in. of the light assembly could be articulated to any angle up to 90° from vertical for proper light direction as required in the IHX. A 0- to 240-V variable power supply was built to supply power to the light as required for the particular viewing requirement.

F. Fiber Optics

A fiber-optics assembly (Cat. No. FS-42-60) was procured from the American Optical Company for attachment to the TV camera for an attempt to further investigate the hidden volumes of the diffuser-trough assembly. Of particular interest was the possible location of the broken lower clip.

The fiber bundle was 5 ft long and contained both light-transmission fibers for directing light to the field of view and image fibers. The bundle contained some 125,000 fibers bonded together at their ends and enclosed in an armored stainless steel cable. The cable was very flexible and, in this application, proved really too flexible to be guided into the proper viewing attitude.

The eyepiece end of the bundle incorporated an adjustable focusing ring and was adapted to the camera through a special relay-lens system. The assembly was procured with an auxiliary light source (AO Illuminator, Cat. No. II-80), which provided high-intensity light to a Y connection on the fiber cable; this in turn connected to the light-transmission fibers within the cable.

Very poor results were obtained in the IHX inlet pipe. The fiber bundle was difficult to position, the field of vision was poorly illuminated, and no real picture of objects was ever obtained. The fibers were probably damaged during handling of checkout and during insertion in the IHX. More attention to guiding, lighting, and handling might have helped to make the fiber optics successful.

G. Mockup

A full-size mockup of the inlet-pipe portion of the IHX was fabricated from carbon steel pipe and fittings. This mockup included an access port on the inlet elbow and included the stainless steel evacuation tube. No attempt was made to include the diffuser troughs or supports in this mockup. All tools and procedures were proof-tested in this mockup before use in the IHX.

The mockup, the cost of which was comparatively small, proved to be very valuable; it provided checkout and practice for all operations and thereby minimized the time necessary to perform the various inspections, tests, and repair operations in the IHX.

VI. REPAIR EQUIPMENT

The repair of the heat exchanger was restricted to the removal of the upper support clip and the evacuation tube. The upper clip was removed by twisting back and forth until the 1/4-in. stainless steel rod broke from fatigue. The upper end of the evacuation tube was cut with a TIG welder and the bottom was cut with a pinch-off cutter. This section describes the tools used for these activities.

A. Clip-removal Tools

The upper clip was found bent away from the 1-in. evacuation tube by at least 3/16 in. at the end. This space provided an opening to drive a wedge that could be used to further bend the clip away from the tube. Once clear, the clip could be gripped firmly to twist it off from its support. This activity required a twist tool and a breakoff tool.

Each tool was equipped with a steel-cable lanyard, which was tightened firmly around the clip to prevent loss when the clip broke off. The twist tool at the top in Fig. 50 was shaped to rest saddle-like on the 1-in. pipe and slide under the lip of the clip. It was shaped to capture the end of the clip so that it would not slide off in twisting.

The breakoff tool at the bottom in Fig. 50 was simply a forked pipe equipped with a safety lanyard as before. Each tool was about 12 ft long and was equipped with a pipe handle welded to the upper end of the pipe. The lanyard cables were anchored in place after first being looped around the clip. A simple screw-type takeup arrangement was incorporated in the handle for this purpose.

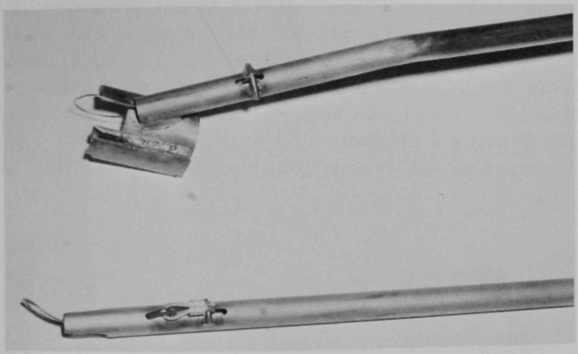


Fig. 50. Tools for Removing Upper Clip. ANL Neg. No. 103-05236.

Fig. 51. Twist-off Tool with Removed Upper Clip. ANL Neg. No. 103-05234.

The tools were used without difficulty to remove the upper clip. Figure 51 shows the clip in the breakoff tool immediately after removal from the IHX.

B. Pinch-off Tube Cutter

A variety of methods were considered for cutting off the evacuation tube near the bottom of the IHX inlet pipe. The most practical and satisfactory method was considered to be the use of a commercially available hydraulic bar cutter from H. K. Porter, Inc., modified as required to cut the evacuation tube.

Figure 52 shows the modified cutter. The cutter was operated by a 4-in.-dia spring-return piston with a thrust rating of 35 tons. The cutter is normally operated with a hydraulic power source, but this was not considered desirable inside the IHX because of the potential for introducing hydraulic oil into the system. Instead, high-pressure argon was used to operate the cutter. Tests showed that an argon pressure of approximately 2000 psi was required to cut off the evacuation tube. This provided a cutoff thrust force of about 24,000 lb.

The actual cutting was performed by slipping the cutter head over the end of the evacuation tube and lowering the cutter with an attached support rod and cable until the clearance between the tube and the 12-in. pipe precluded further lowering of the cutter. Argon pressure of about 200 psig was then applied to flatten the tube but not cut it, so that additional clearance could be obtained to again lower the cutter. This was repeated until the cutter was about 6 in. from the bottom of the tube. At this point, the full bottle pressure (2000 psig) was applied to the cutter piston and the tube was cut cleanly off, leaving a pinched-shut stub. Figure 24b, a photograph of the removed portion of the evacuation tube, shows how the tube was flattened and pinched off.

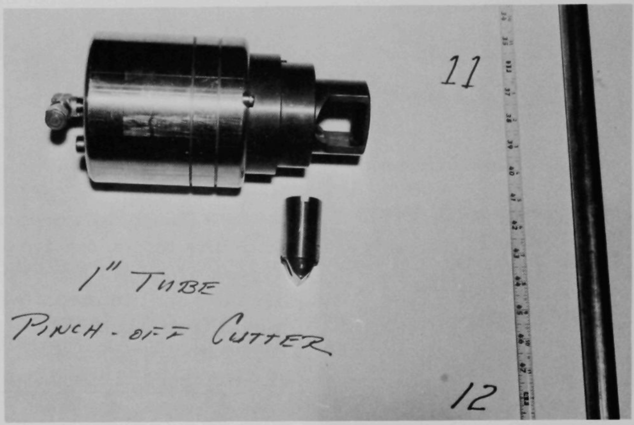


Fig. 52. Pinch-off Cutter for Removing Evacuation Tube. ANL Neg. No. 103-05373.

VII. EVACUATION TUBE AND ITS FAILURE MECHANISM

The evacuation tube was originally provided for the purpose of removing essentially all the liquid sodium from the tube side of the IHX if operation or maintenance should require it. The tube had never been required before this incident.

The evacuation tube as originally installed is shown in Figs. 3 and 4. The tube was supported at four locations: (a) at the top, by welding, where the tube penetrated the 12-in. inlet elbow, (b) about 6 ft from the top, by a support clip welded to the 12-in. inlet pipe and bent around the tube, (c) about 19 ft from the top, by a second clip, and (d) at the bottom (about 21 ft down) by welding to a lower terminal piece, which penetrated and was welded to the diffuser troughs.

The evacuation tube was fabricated from 1-in.-OD, 0.065-in.-wall seamless tubing conforming to ASTM A-213, Grade TP304 stainless steel. The tube as installed was relatively flexible. Only small forces were needed to produce the vibrational amplitude required for the tube to strike the wall of the 12-in. pipe. The best evidence of this was the observation that in the mockup of the inlet pipe, forces of only a few pounds applied to the 1-in. tube would excite the tube and cause a noise that sounded like that originating from the IHX.

The 1-in. tube in the IHX had a calculated natural frequency corresponding to the approximate frequency associated with the observed banging. Because of the 12-in. 90° inlet elbow of the IHX, the incoming flow (~15 ft/sec) could impinge on and produce a substantial force on the 1-in. tube. There also existed a Bernoulli force because of the velocity profile near the wall of the 12-in. pipe. This caused a differential force across the 1-in. tube that tended to center the tube in the flow stream. Either of these forces could easily have been the forcing function that initiated vibration of the tube. In all probability, the tube had been vibrating since the IHX was initially placed in operation. The resulting cyclic forces and wear at the two support clamps finally caused the lower clip to break off. This probably changed the vibrational mode and/or increased the amplitude of vibration so that the tube began impacting against the 12-in. pipe, which produced the audible noise detected on November 14, 1970.

The power level of the reactor has been gradually increased through the years, as shown in Table IV.

TABLE IV. Maximum Reactor Power, 1964-1970

Year	Maximum Reactor Power, MWt
1964	37
1965	45
1966	45
1967	45
1968	50
1969	50[a]
1970	62.5

[a] 62.5-MW test run for 517 MWd.

The flow rate of the secondary sodium system varies with reactor power level; therefore the IHX has operated under varying conditions throughout this period. The flow rate of the secondary system varies from near zero at zero reactor power to 5400 gpm at 62.5 MWt. The average coolant velocity in the inlet pipe at maximum flow is 14.6 ft/sec. Since the noise was detected only about 40 days after the reactor power level was increased from 50 to 62.5 MWt, it appears likely that the resultant increase in secondary sodium flow accelerated the failure of the support clip. The failure would probably have occurred without the power increase; it just would have taken longer.

No explanation has been formulated as to why one clip, particularly the lower one, should break off before the other, unless the weld at the lower clip was faulty.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The experience gained from examination and repair of the IHX leads to the following conclusions and recommendations. First are those that relate to working on an existing IHX or similar equipment. They are:

1. When practical, full-scale mockups should be used to proof-test inspection and repair equipment and procedures. These mockups should also be used as personnel training aids.

2. Any unique welding, cutting, and inspection activities should be performed on test specimens. Detailed procedures of these activities should be prepared and rigorously followed.

3. Tools for performing the various inspection and repair activities should be as simple as possible. Several simple tools of rugged construction are generally cheaper to fabricate and easier to use than more complex tools designed to perform several tasks.

4. Commercially available equipment, modified to suit specific requirements, is cheaper and can be obtained much more quickly than specially procured or fabricated items.

Second, for future designs of an IHX or similar equipment:

1. The design should include only those features that are necessary. Consideration should be given to ease of fabrication, inspection, installation, testing, maintenance, and repair.

2. Convenience features, such as the evacuation tube, should be left out when an alternative means exists for doing the job. For example, a temporary evacuation tube, which could be inserted through a flanged, seal-welded access port, could be used in place of a permanently installed tube.

3. All components subject to flow forces should be analyzed for possible induced vibration. Appropriate measures should be taken to prevent undesirable or damaging vibration.

4. Careful consideration should be given to radiation-shielding requirements. It may be desirable to provide external shielding, if necessary, instead of complicating the design with such things as the offsets in the inlet and outlet pipes. These offsets definitely complicated the access for inspection and repair.

5. Features should be incorporated in the original design that permit reasonably easy access for inspection and repair. Of primary consideration are (a) tube inspection, (b) tube plugging if required, (c) examination of tube-to-tube sheet welds, and (d) inspection of the inlet baffles or orificed region.

6. The original design should include contingency planning for removal, repair, and reinstallation of the tube bundle, such as provision of an adapter flange for mounting a pulling caisson. The planning should include a reasonable concept of the required procedures.

APPENDIX A

Noise-analysis Summary

1. IHX Noise-testing Program and Results

The investigational noise-test program, as discussed in several portions of Sect. III, consisted of monitoring and analyses of the following IHX configurations:

a. System operating with flow while banging noise existed and before any disassembly began ("as found" condition).

b. IHX mockup with ball impactor.

c. IHX inlet-pipe wall with ball impactor.

d. IHX lower center post and diffuser troughs with ball.

e. System with flow after completion of repair.

In addition to the ball impactor and the self-excitation from sodium flow, supplementary noise sources were used, such as rubbing the inlet pipe, tapping it with a ball-peen hammer, and directly exciting the evacuation tube from the outside of the IHX.

Accelerometers were positioned at the locations shown in Fig. 44. Positions 1-3 are permanent and are constructed as shown in Fig. 45. An accelerometer was located on the evacuation tube in position 4 for most of the investigational tests. The other three permanently located accelerometers continue to be monitored during EBR-II operation.

So many frequency components are present in the results that it is impractical, if not impossible, to explain all the resonance modes appearing in the measured spectra. The approach used in this discussion is to calculate expected resonances and then examine the measured spectra for resonance peaks falling near the calculated values. Equations, references, constants, and results are listed in the following discussion.

a. Low-frequency Region

(1) Calculated and Measured Resonant Frequencies of IHX Evacuation Tube. The equations for calculating the resonant frequencies of the evacuation tube are taken from Ref. 6, pp. 61-8 and 61-9. The equation for free-vibration resonances of a beam is applicable to both the evacuation tube and inlet pipe. The equation is

$$f_n = \frac{\lambda_n^2}{2\pi \ell^2}\sqrt{\frac{EI}{m}}, \tag{1}$$

where

E = modulus of elasticity,

I = area moment of inertia,

m = mass per unit length = ρA,

ℓ = distance between restraints,

ρ = material mass density,

A = cross-sectional area of the beam (tube),

and

λ_n = eigenvalues of the system. These eigenvalues are functions of the constraints effective on the tube.

For both evacuation-tube ends fixed,

λ_n = 4.73, 7.85, 11.0, 14.1, for n = 1, 2, 3, and 4

and

$$\lambda_n \simeq \frac{2n + 1}{2}\pi \text{ for n large.}$$

For one fixed and one pinned evacuation-tube end,

λ_n = 3.93, 7.07, 10.2, 13.35, for n = 1, 2, 3, and 4,

and

$$\lambda_n \simeq \frac{4n + 1}{4}\pi \text{ for n large.}$$

Case 1: With the sodium removed from the IHX and both clips removed (see Fig. A.1), the following data were used as input for Eq. 1:

$E = 29 \times 10^6$ lb/in.^{2} at 70°F (Ref. 7),

$A = 0.184$ in.^{2},

$I = 0.0203$ in.^{4},

ρ = stainless steel mass density = 7.42×10^{-4} lb-sec^2/in.^{4},

and

ℓ = length of evacuation tube between supports = 256 in.

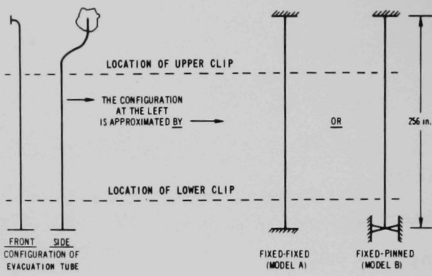


Fig. A.1

Evacuation-tube Configuration for Calculation for Case 1. ANL Neg. No. 103-P5243.

Visual observation of the evacuation tube in free vibration, excited by striking the tube from outside the IHX, showed the preferred mode of vibration to be in the plane perpendicular to the plane containing the pipe bend. The calculated and measured values are shown in Fig. A.2 and the Fourier spectra in Fig. A.3. The amplitudes of the measured spectra are arbitrary, since the data were recorded during decay of tube vibration. Note that the measured resonances agree reasonably well with the calculated values for Model A (tube fixed at both ends).

Case 2: With the IHX filled with sodium and the evacuation tube restrained by the upper clip (see Fig. A.4), the following data were used as input for Eq. 1:

$$\ell = 177.5 \text{ in. for lower section,}$$

$$\ell = 78.5 \text{ in. for upper section,}$$

$$E = 26.8 \times 10^6 \text{ lb/in.}^2 \text{ at } 600^\circ\text{F (Ref. 7),}$$

$$I = 0.0203 \text{ in.}^4,$$

and

$$m = \rho A = \rho_{ma} A_0 + \rho_t A_t.$$

The expression ρA includes an estimated amount of sodium set in motion by the vibrating tube and is found by letting

$$A_0 = \frac{\pi}{4}(D_i^2 + D_0^2),$$

where

$$D_i = \text{tube ID} = 0.875 \text{ in.,}$$

$$D_0 = \text{tube OD} = 1.000 \text{ in.,}$$

$$A_t = 0.184 \text{ in.}^2,$$

$$\rho_{ma} = \text{sodium mass density} = 8.1 \times 10^{-5} \frac{\text{lb-sec}^2}{\text{in.}^4},$$

and

$$\rho_t = \text{stainless steel tube mass density} = 7.42 \times 10^{-4} \frac{\text{lb-sec}^2}{\text{in.}^4}.$$

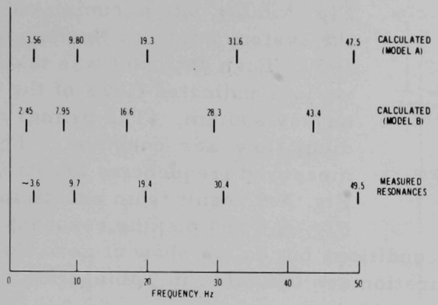


Fig. A.2

Comparison of Calculated and Measured Resonant Frequencies for Case 1. ANL Neg. No. 103-P5243.

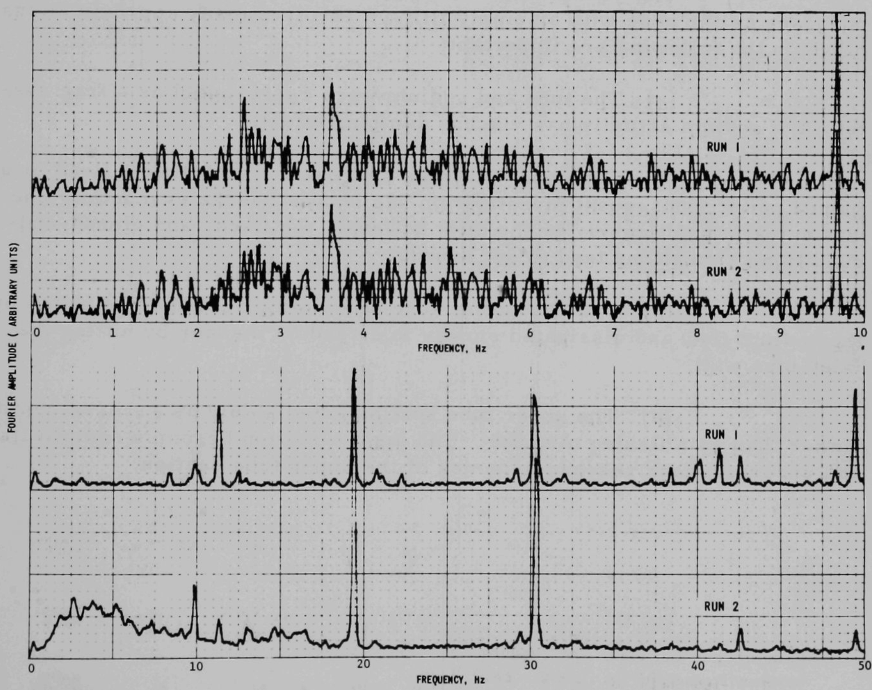


Fig. A.3. Measured Resonant Frequencies of IHX Evacuation-tube Vibration with Both Clips Removed and No Sodium. ANL Neg. No. 103-P5242.

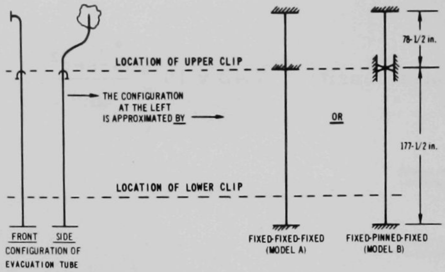


Fig. A.4. Evacuation-tube Configuration for Calculation for Case 2. ANL Neg. No. 103-P5241.

The computed and measured resonances for Case 2 for the lower section (ℓ = 177.5) are presented in Fig. A.5. The relative amplitude versus the frequency is shown in Fig. A.6 for data accumulated with the system intact on November 17, 1970. Each data plot was taken for various indicated flows of the secondary sodium. (The primary sodium flow was constant.) The measured frequencies shown in Fig. A.5 result from examining Fig. A.6 and picking resonant frequencies that appear during flow conditions but do not show at zero flow. The detailed results of this examination are tabulated in Table A.1.

The configuration of Case 2 is not as simple for analysis purposes as the case with an empty IHX. It involves many approximations of which the following are important:

(a) The tube and sodium were represented as a free system; the sodium actually has viscous damping effects.

(b) The upper clip was represented as either a fixed or a pinned point. Subsequent investigation has shown that the evacuation tube was actually held loosely by the clip; however, the fixed- and pinned-end-condition calculations tend to set bounds.

(c) The evacuation tube was continuously being excited by the sodium flow and dissipated energy in a random manner by hitting the inlet-pipe wall.

(d) The upper tube section acted solely as a stiff transmitter rather than as a flexing member. The approximation becomes complicated and uncertain near resonance modes of the upper tube section.

Fig. A.5

Comparison of Calculated and Measured Resonant Frequencies for Case 2. ANL Neg. No. 103-P5241.

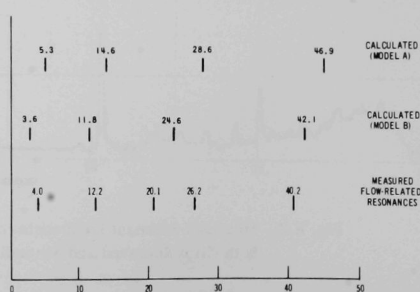


Fig. A.6. Noise Spectrum of IHX with Varying Secondary Flow Taken November 17, 1970 (accelerometer on evacuation tube). ANL Neg. No. 103-P5245.

TABLE A.1. Comparison of Calculated and Measured Resonances of Evacuation Tube When IHX Is Filled with Sodium

	Calculated Frequencies, Hz					
	Upper $78\frac{1}{2}$ in. of Tube		Lower $177\frac{1}{2}$ in. of Tube			Flow Rate at Which Measured Resonance
Mode, n	Fixed-Fixed	Fixed-Pinned	Fixed-Fixed	Pinned-Fixed	Measured Frequencies	Appeared[a]
1	27.0	18.7	5.3	3.6	4.0	1, 2, 3, 4, 5
					8.1	1, 2, 3
					10.1	1, 2, 5
2	74.4	60.4	14.6	11.8	12.2	1, 2, 3, 4, 5
					15.1	1, 3, 4
3	146	125.6	28.6	24.6	20.1	1, 2, 3, 4, 5
					26.2	1, 2, 3, 4, 5
					35.0	1, 3, 4, 5
					36.2	1
4	240	215	46.9	42.1	40.2	1, 2, 3, 4, 5
					44.2	1
					48.2	1

[a]Indicates the appearance of resonance peaks in the spectra for the following secondary-flow levels: (1) 79%, (2) 70%, (3) 60%, (4) 45%, and (5) 27%. Peaks present at 0% flow were not considered to be flow-rated and were not included in this table.

The calculated resonance modes for the pinned-fixed condition, Model B, of the lower portion of the tube offer reasonable correlation with measured modes that are present at all except zero flow of the secondary sodium. Consequently, the amplitudes of these frequencies appear to be flow-dependent.

(2) Calculated and Measured Resonant Frequencies of IHX Inlet Pipe. The following data were used for Eq. 1 as applied to the inlet pipe

E = 26.8×10^6 lb/in.^{2} at 600°F (Ref. 7),

d_i = inside diameter = 12.25 in.,

d_0 = outside diameter = 12.75 in.,

ρ_t = stainless steel density = 7.42×10^{-4} lb-sec^2/in.^{4},

ρ_{Na} = sodium density = 8.1×10^{-5} lb-sec^2/in.^{4},

and

ℓ = length between the bottom of pipe and point where it exists from top of IHX = 225 in.

The results of this calculation are listed in Table A.2.

TABLE A.2. Calculated Resonant Frequencies of Inlet Pipe, Hz

	Fixed-Fixed Ends		Fixed-Pinned Ends	
Mode, n	Empty	Sodium-filled	Empty	Sodium-filled
1	59.0	39.7	40.7	27.4
2	162.5	109.3	131.8	88.7
3	319.3	214.6	274.4	184.5
4	524.2	352.5	469.7	316.0

Resonance modes were measured on the sodium-filled system, with the self-generated noise, at frequencies of 26, 29.5, 39.0, and 100 Hz. Bending-mode resonances on the inlet pipe do not appear in the ball-drop data.

b. High-frequency Region

The circumferential modes of vibration at the inlet pipe are most apt to be excited by striking the pipe wall by the ball impactor. Reference 6, pp. 61-25 and 61-26, gives the frequencies for the circular modes in the extensional case as

$$f_n^i = \frac{1}{2\pi}\frac{\lambda_n^i}{a}\sqrt{\frac{Gh}{\mu}},$$

where

f_n^i = resonance of the nth mode for the ith root,

i = 1, 2, 3, for the three roots of each eigenvalue,

n = 0, 1, 2, 3, ..., eigenvalue number or number of complete circumferential waves,

a = mean radius of the cylinder = 6.25 in.,

G = modulus of rigidity = 10.3×10^6 lb/in.^{2} (600°F),*

h = wall thickness = 0.25 in.,

and

μ = mass per unit area of the wall at the mean radius = $1.88 \times 10^{-4} \dfrac{\text{lb-sec}^2/\text{in.}}{\text{in.}^2}$.

The form of the vibrational modes is shown in Fig. A.7.

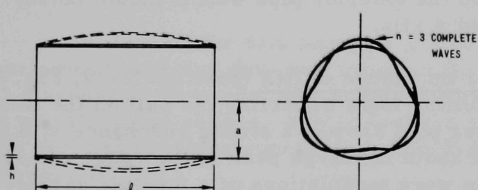


Fig. A.7

Modal Shapes for Circumferential Vibration Modes of IHX Inlet Pipe

Circular frequencies were calculated using eigenvalues as tabulated on p. 61-26 in Ref. 6 for $\ell/a = \infty$. (The eigenvalues for $\ell/a = \infty$ are assumed to be close approximations to those obtainable for the inlet pipe where $\ell/a = 36$.)

The circular frequencies between 0 and 10 kHz are listed below:

f_0^3 = 5.04 kHz (λ_0^3 = 1.691);

f_1^2 = 2.98 kHz (λ_1^2 = 1.000);

f_1^3 = 7.13 kHz (λ_1^3 = 2.391);

f_2^2 = 5.96 kHz (λ_2^2 = 2.000);

f_3^2 = 8.94 kHz (λ_3^2 = 3.000).

These values essentially set a range in which to observe circular resonance modes. A large number of resonances in this high-frequency

*Using Poisson's ratio (ϵ) = 0.3 and $G = \dfrac{E}{2(1+\epsilon)}$.

range were observed as a result of exciting the IHX. Observations taken from each accelerometer are described below.

(1) <u>Accelerometer on Inlet Pipe</u> (Position No. 1, Fig. 44)

(a) The ball-impactor data in both the mockup and the IHX showed similar patterns for impact on the inlet-pipe wall. The frequency of the spectrum generated ranged from about 2.5 to about 10 kHz. The mockup had a somewhat thicker wall and showed a slightly higher range.

(b) The impact of the ball on the diffuser troughs excited dominant resonances at 2.6, 4, and 4.2 kHz. These resonances also appeared in several of the records where excitation was caused by impacting the ball against the pipe wall.

(c) Impacting the ball on the center post excited a resonance at 2.6 kHz.

(d) Rubbing on the exterior pipe wall (random noise) excited resonances near 2.6 and 4 kHz.

(2) <u>Accelerometer on Flange of IHX</u> (position No. 2, Fig. 44). In all cases, the spectrum resulting from impacting the ball on the inlet pipe, diffuser troughs, or center post showed a strong resonance at 6.6 kHz, with smaller peaks distributed about the large peak in the range of ±500 Hz. (It appeared that the side bands were modulations of a 6.6-kHz carrier frequency by a frequency of about 100 Hz.)

(3) <u>Accelerometer on Outlet Pipe of IHX</u> (Position No. 3 Fig. 44)

(a) Frequencies were excited in the outlet pipe in the 1- to 5-kHz region, when the ball was impacted near the bottom of the inlet pipe, on the troughs, or on the center post. However, when the ball was impacted at points above the bottom of the inlet pipe (i.e., higher than 18.5 in.), higher frequencies (4-9 kHz) tended to be excited on the outlet pipe.

(b) Data from the self-generated noise tended to show a spectrum that peaked in the 1- to 3-kHz region.

(4) <u>Accelerometer on Evacuation Tube</u> (Position No. 4, Fig. 44)

(a) Noise resulting from the "as found" IHX contained frequency spectra in two ranges: 300-3000 and 6000-8000 Hz.

(b) The ball-dropping experiment produced a frequency spectrum in the range of 6000-9500 Hz with the ball impacting just above the diffuser troughs (18.5 in.). As the impact point was moved higher, the frequency spectrum expanded slightly and assumed a shape more nearly like the actual spectrum taken November 14, 1970.

(c) Dropping the ball into the diffuser troughs produce a spectrum with a sharp resonance peak at 5700 Hz and repeatable spectra about the frequency of 8000 Hz. Impacting the second trough produced a sharp resonance at 2100 Hz.

(d) Impacting the ball on the center post produced a sharp resonance peak at 5600 Hz and another at 9250 Hz. Otherwise, very little noise was generated except white noise.

c. Summary

The free oscillations of the evacuation tube (sodium removed from IHX) were identified clearly by measurements; further, the type of end attachment was identified by comparing measured and calculated values.

It appears that most of the high-frequency resonances measured on the inlet and outlet pipes can be associated with circular vibrational modes of the pipes, plus additional harmonics due to irregularities, non-linearities, and modulations.

Much of the data analysis has been retrospective, since only a minor amount of noise data was taken on the IHX before the November 14, 1970 discovery. However, this analysis does indicate that the evacuation tube was the noise source. It also lays the groundwork for future monitoring of the IHX and provides quantitative data for relation to possible future disturbances.

2. Comparison of IHX Noise Signatures before and after Repair

Monitoring of the IHX during the startup and operation of EBR-II in the first part of Run 47B (after the repair was completed) showed that the IHX operated "quietly." The term "quiet" is used in the sense that the IHX did not emit the random noise bursts discovered at the end of Run 47A. The quieter operation was verified qualitatively by simple listening, and quantitatively by Fourier analysis of the noise spectra.

Comparison of the IHX noise spectra when the noise bursts were present with the noise spectra measured during the startup of Run 47B (see Fig. A.8) readily shows the much quieter IHX operation after repair. The 2.7-kHz peak is present in both analyses and corresponds very well to the fundamental circular resonance frequency (2.98 kHz) calculated for the inlet pipe.

Peaking of the spectra in the 2.6- to 2.7-kHz region was evident in the noise from all three accelerometer positions. This frequency is probably associated with the fundamental circular resonance frequency of the inlet and outlet pipes. The appearance of this frequency on the flange accelerometer is probably caused by driving of the flange by the inlet and outlet pipes.

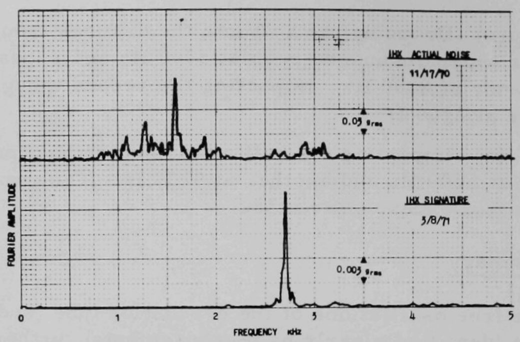


Fig. A.8. Noise Signature for IHX Outlet Pipe at 62.5-MWt Reactor Power before and after Repair. ANL Neg. No. 103-P5251.

Examination of the low-frequency region (0-500 Hz) revealed mostly 60 Hz and its harmonics, especially 120 Hz, due to stray pickup.

APPENDIX B

Welding Procedures and Records

All welding was accomplished by procedures and a welder that were qualified in accordance with Sect. IX of the ASME Boiler and Pressure Vessel Code. Welding was with either Type 304 or 304L stainless steel base material and was performed by the tungsten-inert-gas (TIG) process using Type 308L consumable inserts and filler wire. Records of the qualification of the procedures and welder are maintained on file by Argonne National Laboratory.

Because of the unusual configuration of the elbow-cutout weld, the welder was required to demonstrate that the weld could be accomplished, as well as demonstrate his ability, by making a test weld on a duplicate elbow. Several additional test welds were made of the square corners. These welds were examined by sectioning and radiography. The welder in these tests demonstrated with a high degree of confidence that he could successfully accomplish the required welding. In the process of test welding, it was found necessary to accomplish the root-pass welding by a sequenced procedure that minimized distortion of the weld joint due to weld-metal shrinkage.

The detailed sequenced procedure for making the elbow-cutout weld is given as an attachment to this appendix. Included in this procedure are the details of capping the evacuation-tube penetration. Each weld joint made was identified by a joint number as shown, and inspection record forms were completed and are on file at Argonne National Laboratory, EBR-II site.

ATTACHMENT. Procedure for Closure Welding of the IHX Inlet Elbow

1. Job Description

Procedure for closure (welding) of the intermediate heat exchanger access hole.

2. Personnel Required for Job

(a) Job supervisor

(b) Welder and helper

(c) Inspector

(d) Radiologist

3. Services Required

(a) TIG welding machine

(b) 60-psig argon supply; argon manifold or bottles

4. Cleanliness Requirements

All tools must be cleaned with acetone or alcohol prior to use.

5. Inspection Requirements

Inspect area for cleanliness. Remove all loose objects from the exclusion area. All tools are to be logged in and out of the area. Weld inspection requirements are listed in this procedure.

6. Containment

Containment will be maintained by use of either the access port, a plastic bag, a catch pan inserted inside of the elbow, or the cutout section that is to be rewelded into place. Argon is expected to leak out during most of the operation. Positive argon pressure will be maintained within the system by a supply connected to the evacuation tube.

7. Procedure

7.1 Prepare surfaces for welding as follows:

(a) Using a plastic bag for containment, wire-brush clean the inside surface of the elbow over an area extending at least 1 in. from the weld joint. Use an air motor powered with 60-psig argon. Relieve excess pressure ($>$4 in. H_2O) by bleeding argon out of the plastic bag.

(b) Using the catch pan inserted inside the elbow to catch debris, file and/or emery cloth the weld surface as required for final fitting and cleanliness.

(c) Using a damp cloth (water), wipe clean the entire weld-joint surface.

7.2 Insert the prepared elbow-cutout section into the prepared hole in the elbow. Establish an argon purge into the system by way of the evacuation-tube connection.

7.3 Remove the access port, and clean off the RTV sealant from the elbow surface.

7.4 Weld the cutout section into the inlet elbow by following the steps listed on pp. 76 and 77.

Caution: During welding of the root, second, and third passes, the internal argon pressure must be maintained at a positive value less than 1/2 in. H_2O.

7.5 Using the specified weld procedures, cap the evacuation tube as shown in Fig. B.1. Inspect each weld pass with liquid penetrant.

7.6 Weld into place the evacuation-tube containment cap as shown in Fig. B.1. (Also see Fig. B.2.) Inspect each pass of all welds with liquid penetrant.

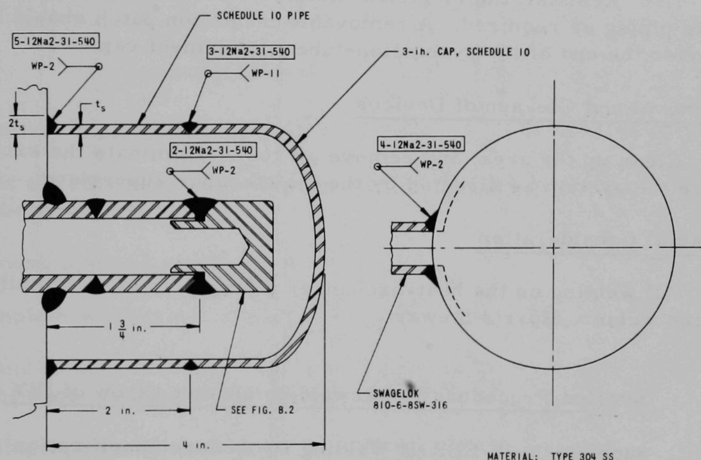


Fig. B.1. Containment of Evacuation-tube Connection

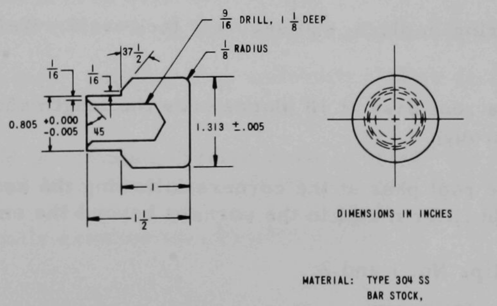


Fig. B.2. Plug for Evacuation Tube

7.7 Using the Swagelok fitting on the containment cap, pressurize the cap with 15-psig argon, and inspect for leaks using the USON argon-leak detector. After a satisfactory leak test, disconnect the argon supply and immediately replace the Swagelok cap, leaving the containment cap filled with argon at atmosphere pressure.

7.8 With the secondary system pressurized with argon to operating pressure, inspect the welded patch for leakage using the USON argon-leak detector.

7.9 Ensure that all welds are properly identified and that the attached weld-inspection sheets are filled out.

7.10 Reinstall the electrical heaters on the secondary sodium piping. Insulate piping as required. A removable insulation patch should be provided over the end of the evacuation-tube containment cap.

8. Removal and Cleanup of Devices

Clean up the area, and remove all tools. Eliminate the exclusion area. Restore the system as directed by the maintenance supervisor.

9. Special Consideration

All welding on the heat-exchanger piping is to be accomplished by the qualified welder, Morris Stewart.

Detailed Procedure for Rewelding of Inlet Elbow of IHX

Supplement to EBR-II Welding Procedure Specification
No. WP-11 (sequence mandatory)

Refer to Fig. B.3.

1. Fit the Y-ring in place, and securely tack-weld. Weld clips 1-6 to the elbow.

2. Fuse in the root pass at 10 places over the length shown, following the sequence A through J.

3. Fuse in the root pass at the corners following the sequence 1 through 8 as shown. Add filler metal in the corners beyond the end of the Y-ring.

4. Remove clips No. 1 and 2.

5. Complete welding of the root pass across the top.

6. Complete welding of the root pass across the bottom.

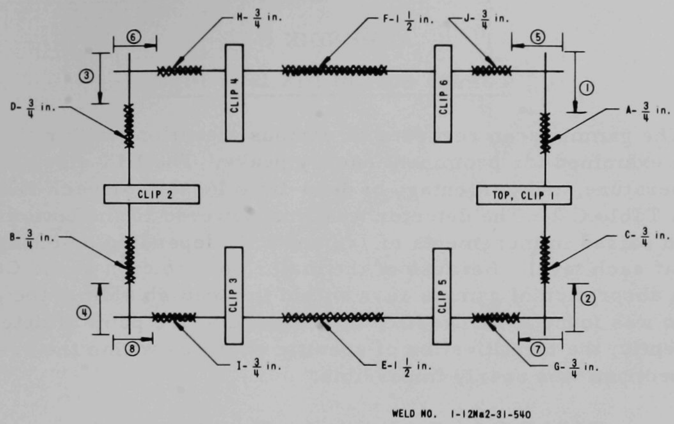


Fig. B.3. Root-pass Sequence for Welding Cutout in Elbow of IHX

7. Remove two lower clips, one on each side, No. 3 and 4.

8. Weld the root pass on each side where clips No. 3 and 4 have just previously been removed.

9. Remove last two clips, No. 5 and 6.

10. Complete welding of the root pass.

11. Liquid-penetrant-inspect the root pass and the surface of the elbow where the support clips were welded.

12. Radiograph the root pass of the weld before proceeding.

13. After the root pass has been accepted, complete the second and third passes over the root pass. Limit the width of the weave, and do not attempt to put in a heavy weld bead over the root pass. Be extremely careful not to burn through the root pass. Liquid-penetrant-inspect each pass.

14. Complete the weld, building it up uniformly. After each pass, allow the weld to cool, and liquid-penetrant-inspect.

15. After the weld is completed, grind smooth the surface of the weld. Weld reinforcement must be in the range of 0 in. minimum to 1/16 in. maximum.

16. Radiographically examine the completed weld.

APPENDIX C

Gamma Scan of IHX Inlet Pipe

The gamma scan recorded at various elevations within the IHX inlet pipe was examined for prominent energy peaks. The IHX elevations, detector temperature, and percentage of dead-time losses for each record are shown in Table C.1. The detector was first lowered to the bottom of the IHX, then raised in increments of 1/2 and 1 ft, depending on change in total activity at each level. Because of the major contribution of the Compton effect on absorption of gamma rays within the lead shielding, the gamma spectrum was found to be drastically degraded at the point of detection. Consequently, the identification of specific energies within the resulting broad spectrum was nearly impossible.

TABLE C.1. Conditions for Each Position for Gamma Scan of IHX Inlet Pipe

Scan Position,[a] ft	Temperature, °F	Dead Time, %
22.1	76	17
21.5	82	14
21	86	24
20.5	90	25
20	93	24
19	99	21
18	103	21
17	108	21
15	112	21
14	116	20
13	118	16
12	122	15
11.5	123	7
11	123	4
10	125	3
9	128	5
8	126	3

[a]Distance from top of shutter plate in access port.

A typical example taken at about 12 ft down in the IHX with a counter dead time of about 12% is shown in Fig. C.1.

This record indicates a broad peak in the range of 800-850 keV. The shift of the apparent energy location of this peak (to 700-750 keV) with increase in detector temperature (72-122°F) was similar to the shift observed with a ^{137}Cs calibration source. A record was taken using the ^{137}Cs source before and after this examination.

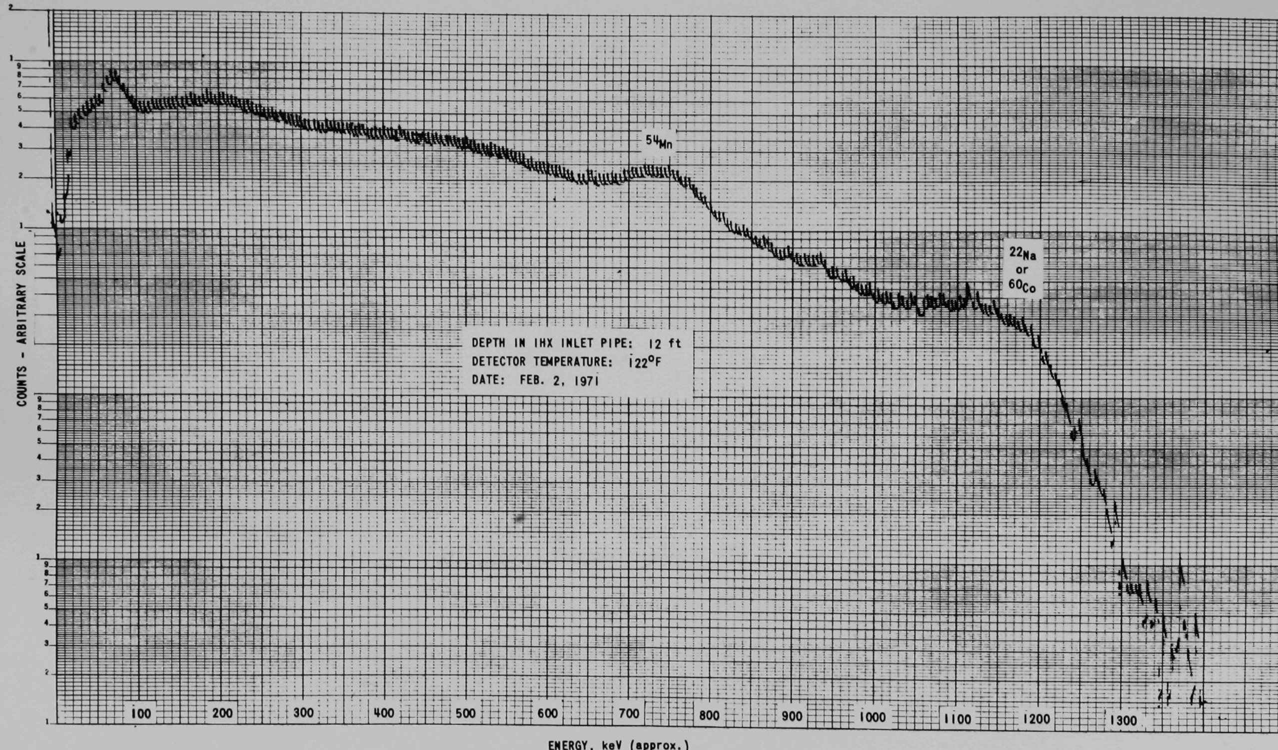


Fig. C.1. Gamma-ray Energy Spectrum of IHX

The gamma ray with the highest probability of occurring in the energy range of 800-850 keV is ^{54}Mn (840 keV, half-life 314 days). The falloff of the gamma-ray spectrum occurs at about 1.30 MeV, which coincides with the ^{60}Co (1.33-MeV) and the ^{22}Na (1.28-MeV) gamma-ray energies. Since the detector was below the upper level of the primary sodium, ^{22}Na is the most likely origin of the higher-energy gamma-ray spectrum.

Evaluation of the IHX gamma spectrum is a part of an overall gamma-ray investigation of power-plant items and is described more fully in Ref. 5.

APPENDIX D

Effect of IHX Noise Problem on EBR-II Operation and Summary of Repair Effort

On November 14, 1970, when the reactor plant was shut down because of the observed IHX noise, plans were being finalized for a scheduled plant shutdown on about January 1, 1971, for two months for numerous maintenance items and modifications. Because it was immediately obvious that the IHX could not be repaired without an extended shutdown, the other plant maintenance and modifications were rescheduled to start as soon as possible. The major maintenance item to be performed was examination of the No. 1 primary coolant pump (see Ref. 3).

Many shutdown items could not be immediately started (or finished) with the earlier shutdown because all preparatory work was not complete. In addition, some equipment and parts were not scheduled to arrive until later. Because of this, the work during the first several weeks of the shutdown was not as efficiently accomplished as it would have been if two more months of preparation time had been available. In spite of these difficulties, the secondary sodium system was refilled on February 16, 1971, almost exactly three months after the noise was observed in the IHX. Hence, it is concluded that the IHX noise investigation and repair activities resulted in the loss of no more than one month of plant availability. Manpower effort and material costs directly related to the IHX problem are listed in Table D.1.

TABLE D.1. Summary of Direct Manpower Effort and Material Cost for IHX Repair

I. Manpower Effort, man-months

	Direct Repair Effort			Direct Support Effort						
				Noise Analysis		Analytical Laboratory		Viewing Techniques		
Category	Planning and Design	Mockup	IHX Repair	Mockup	IHX	Mockup	IHX	Mockup	IHX	Total
Supervision	1.0	0.3	0.3	-	-	-	-	-	-	1.6
Engineering	3.0	1.0	2.4	0.5	2.0	0.1	2.0	1.0	1.0	13.0
Technician	0.6	-	2.5	0.3	1.1	0.1	1.6	1.7	1.6	9.5
Machinist	-	0.8	1.6	0.5		1.0		1.5		5.4
Welder	-	0.5	0.3	0.1		0		0.1		1.0
Draftsman	0.4	-	-	-		-		-		0.4
Total	5.0	2.6	7.1	4.5		4.8		6.9		30.9

II. Material Cost

Item	Cost
1. Carbon steel piping for mockup	$ 300
2. Stainless steel elbow for welding qualification	650
3. Spare stainless steel elbow with certification	1,300
4. Butt welding cap with certification papers	200
5. Hydraulic tube cutter	1,300
6. Fiberscope and accessories	2,800
7. Television equipment	3,350
8. Noise-analysis equipment	2,900
9. Miscellaneous tools, instruments, wire, tubing, pipe, etc.	1,200
Total	$14,000

ACKNOWLEDGMENTS

The successful examination and repair of the IHX results from the efforts of many people whose interest was to effect the repair as expeditiously as possible so that EBR-II downtime would be minimized. We wish to acknowledge the following groups and individuals for their significant efforts:

EBR-II Training Personnel for development and operation of TV equipment.

J. R. Karvinen and C. Price for noise measurement and analysis.

C. Smith for gamma measurements.

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M. Stewart for welding performed on the IHX elbow.

R. A. Noland for design and procurement of the evacuation-tube cutoff tool.

K. Ferguson for design of the periscope viewer.

We wish to thank Mr. Ken P. Johnson of Atomic Power Development Associates for advice and counsel and for the loan of the large borescope and the high-intensity quartz lamp. His consultation in the early portion of this investigation was most helpful and was appreciated.

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